LEARNING
Science
Thru
Inquiry

Deep Understanding of Science for All Students at All Levels

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Idaho Title I Workshop
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in
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Deep Understanding of Science for All Students at All Levels
Reconsidering What It Means To Learn Science Through Inquiry

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The plan:

The objective of science teaching
Freedom to construct explanation
- The Farmer & the Seeds
- the objective of science – Max Jammer

Developing new understanding of a phenomenon in science
- Light rays, images and lenses activities
- How and why we change our understanding – Jean Piaget
    - Piaget's theory of cognitive equilibration–short presentation
- Strategy for engaging students in developing deep understanding
    - The light activities are an example
    - Induce disequilibration and facilitate resolutions–short presentation

Communication for teachers
- Communication Handout–followed by short discussion
- A view of communication (to read later)
- Implications for communication between teacher & students and students & Students–short discussion

Why worry about change in understanding in science classes?
- Hestenes excerpt (to read later)

How to make a science class not science
- An exercise in language and science followed by short discussion

"Really" Learning?
- The cost of growth – Wm. G. Perry, Jr.
- The central puzzles of learning – Howard Gardner

For those who want to go further
- the nature of knowledge, a short book chapter by Ernst von Glasersfeld
    - This was not in the original manual, but it is in this pdf version of the manual.

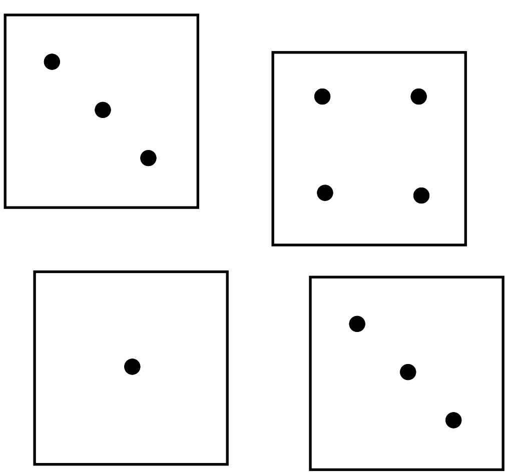
The Farmer and the Seeds

There once was a farmer, new to farming. She began as anybody would, taking the advice of more experienced farmers using tried and true methods. The particular crop that this region was known for is planted much like the corn we grow in North America, called maize in many other places in the world. The standard practice is to drop several kernels or seeds of corn at each location where we want a plant to grow. One imagines this may be because not every seed is fertile and one wants to guarantee that a plant comes up at each planting site. As it happens, the same was apparently the case with the crop of this region, but the crop is not corn.

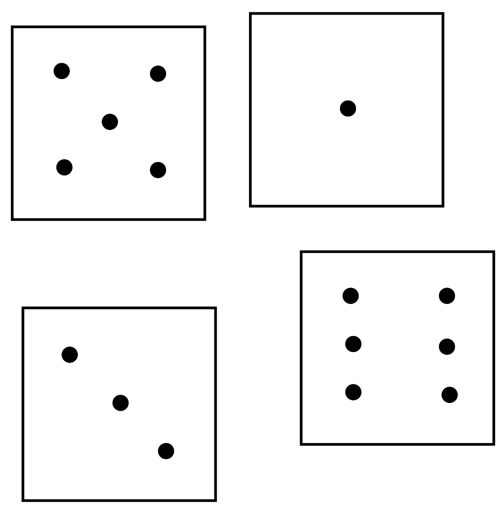
For this crop, the tradition is to put four seeds in at each planting site. The seeds for this crop are in the shape of little cubes and they have dots on their sides. So, the novice farmer proceeded to plant her fields in this time-honored manner. But, being a novice and not knowing what to wonder about or what is not normally wondered about, she began to wonder if the dots had any significance. At first this was because as she eagerly waited for her crop to sprout, she investigated many individual planting sites and noticed that differing numbers of sprouts came up in a cluster at each site. *Could the dot patterns have anything to do with the number of sprouts that came up?*

She decided to put the issue to a test. She gathered a collection of seeds from different sources and at many planting sites she made sure the exact, same dot pattern was facing up at her as she covered them over with dirt. She actually tried two different dot patterns, each at many different planting sites in her fields which you can see below. She watched carefully and found that for the first seed grouping, or dot pattern, four sprouts was always the result. For the second seed grouping, or dot pattern, she found that 6 sprouts was always the result.[1]

First Group



Second Group



The farmer's first two seed groupings:
First group number of sprouts?

Second group number of sprouts?

What do you think?

[1] She wondered about getting 6 sprouts from four seeds, but decided that maybe some of these seeds might be compound seeds. She resolved to look into this issue later.

Is it reasonable to imagine that there may be a connection between the dot patterns and the number of sprouts? Why do you think so?

What schemes can you come up with that would reliably and accurately predict the number of sprouts based on the dot pattern showing when the seeds are planted?

What does your group think?

When everyone has come up with answers to the above two questions, share yours with your group and listen to the ideas of others. Below on this page write down any new schemes you encounter.

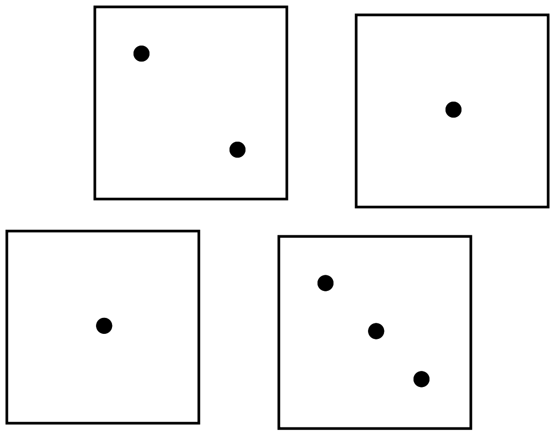
What does the whole class think?
Once your group has developed a list, the whole class will contribute their ideas for schemes to help the farmer. Write down any new schemes you have not encountered previously.

How should we proceed with our list of schemes to help the farmer figure this thing out?

When the class has its list of schemes complete (*for now*) and a response to the question above, turn to the next page.

Making observations. (Testing the schemes)
Another seed grouping the farmer tried:

Third Group



What is the prediction of each of the different schemes the workshop has come up with for this seed grouping? Record your conclusions about the prediction of each of our schemes for this new seed grouping on the previous pages. (Once we have decided what the schemes predict, we will find out what the farmer observed with this grouping.)

The farmer actually found that this grouping produces _ _ seedlings.

How do you think should we make use of the comparison between each of these predictions and the outcome the farmer actually observed?

Compare your answer with those around you. If you hear any different ideas than your own, record them in the space below.

The Farmer and the Seeds

Consider the following questions. <u>First, write down your own personal answers to them</u> and then share your ideas with your group. Write down any new ideas you hear from them.

Where did these schemes we have been discussing come from? Did the schemes we shared with each other exist before we came into the room today?
(Note: This question is not about the elements of the schemes: odds, evens, counting, arithmetic operations, etc., but the decisions as to what elements to use and how to use them.)

How do we know we have figured out all the possible schemes? Please explain your answer

If we have made many different tests of the seed groupings and have found a scheme that has worked on all of them so far, how do we know it will work on the next new test? That is, can we be sure beyond the shadow of a doubt that the scheme will work on the next new test? Please explain your answer.

Can we be sure beyond the shadow of a doubt that we would not find another scheme that would work just as well? Please explain.

If we find just one scheme that works every time, can we be sure it is the TRUE scheme? Please explain.

Is the word "truth" relevant to apply to our schemes? Please explain.

If for some reason you find this activity with a Biological 'flavor' not appropriate for your classes, you can change the setting. Here's an example devised by Andy Johnson.

Have you heard about the lines on the Nazca Plateau? There are a series of lines that run for miles in the desert - they were made by people who simply scooped rocks to the side to make marks on the desert floor. The lines, some of them which run perfectly straight for miles, were made long ago. Many of them show figures that are only visible from high up in the air.

I have an anthropologist friend who is down there in Chile right now. He was studying the Nazca culture, but now he's turning to a new investigation since he found this cave. He followed one of the lines to its end in a hillside and found a hidden cave at the end of the line. The cave is pretty short, but hard to find. At the far end of it my friend found some stacks of square tiles that have dots on them, plus a kind of tilted platform on the wall that has places for four tiles. It looked like the tiles were for putting in the spaces. When my friend put four random tiles in the spaces, nothing happened until he leaned on all for tiles with his hand. He then heard six bonks emanating from somewhere inside the rock! It was really surprising. We don't know what's going on, and this is where you come in. Maybe there is a machine behind the rocks, making the bonks, but we don't know how it decides how many bonks to make. He wants to know whether there is a relationship between the patterns of dots on the tiles and the number of bonks he hears.

As you can see, it is possible to develop what is essentially the same activity with a different context in order to engage your students in the same questions which are really about the nature of explanatory knowledge and experiential knowledge.

the objective of science

Max Jammer

As a result of modern research in physics, the ambition and hope, still cherished by most authorities of the last century, that physical science could offer a photographic picture and true image of reality had to be abandoned. Science, as understood today, has a more restricted objective: its two major assignments are the description of certain phenomena in the world of experience and the establishment of general principles for their prediction and what might be called their “explanation.” “Explanation” here means essentially their subsumption under these principles. For the efficient achievement of these two objectives science employs a conceptual apparatus, that is, a system of concepts and theories that represent or symbolize the data of sense experience, as pressures, colors, tones, odors, and their possible interrelations. This conceptual apparatus consists of two parts: (1) a system of concepts, definitions, axioms, and theorems, forming a hypothetico-deductive system, as exemplified in mathematics by Euclidean geometry; (2) a set of relations linking certain concepts of the hypothetico-deductive system with certain data of sensory experience. With the aid of these relations, which may be called “rules of interpretation” or “ epistemic correlations,” an association is set up, for instance, between a black patch on a photographic plate (a sensory impression) and a spectral line of a certain wavelength (a conceptual element or construct of the hypothetico-deductive system), or between the click of an amplifier coupled to a Geiger counter and the passage of an electron. The necessity for physical science of possessing both parts as constituents results from its status as a theoretical system of propositions about empirical phenomena. A hypothetico-deductive system without rules of interpretation degenerates into a speculative calculus incapable of being tested or verified; a system of epistemic correlations without a theoretical superstructure of a deductive system remains a sterile record of observational facts, devoid of any predictive or explanatory power.

The adoption of rules of interpretation introduces, to some extent, an arbitrariness in the construction of the system as a whole by allowing for certain predilections in the choice of concepts to be employed. In other words, arbitrary modifications in the formation of the conceptual counterparts to given sensory impressions can be compensated by appropriate changes in the epistemic correlations without necessarily destroying the correspondence with physical reality. In consequence of this arbitrariness, scientific concepts “are free creations of the human mind and are not, however it may seem, uniquely determined by the external world.” (Einstein and Infeld, *The Evolution of Physics*, 1938)

When science attempts to construct a logically consistent system of thought corresponding to the chaotic diversity of sense experience, the selection of concepts as fundamental is not unambiguously determined by their suitability to form a basis for the derivation of observable facts.

—p. 2-4, Jammer, Max. ***Concepts of Force***. Dover (1999) originally Harvard University Press, 1957.

DOING

Physics:

Thinking About...

Images from Lenses

Dewey I. Dykstra, Jr.
Boise State University

for

Idaho Title I Workshop

Spring, 2009

in

Boise, Idaho

Preface for the Students

These investigations are the foundation of a course in the study of physical phenomena. This course is probably unlike any you have ever experienced.

Normally in a science course you have come to expect:

- to be *informed* by lecture and the text,
- to *verify* what you have been told in the laboratory exercises, and then
- to *practice* applying what you have learned in problems.

This is not what will happen in this course.

These investigations serve a *very different* purpose than *verification*. In this course, what happens in the laboratory will always precede the discussion in class. These activities are intended:

- First, to get you to ***elicit*** your current ideas about the phenomena and share them with your lab partners.
- Then to give you the opportunity to ***compare*** the ideas you have with the actual behavior of the phenomena.
- Finally, to get you to engage in discussions of your observations and the implications of these observations for your original ideas. Together with your classmates you will ***construct*** new explanations of the phenomena that make sense to us when you decide that the original ideas are lacking in some way.

Normally, in science labs *closure* is the goal; *i.e.*, to *verify and finally "know"* that what you have been told in lecture or the text is "correct." In the investigations in this course *closure* in the laboratory is ***not*** the goal. In fact, the opposite is intended. The hope is that, as of the end of each lab period, you will be in a state of disequilibration, *i.e.* that you will have experienced some aspects of the phenomena involved that *do not turn out as you have predicted* in some significant way. This puts you in the best possible position to participate in the class discussion that will follow the lab experience.

This is really what *Doing Physics* is all about: looking for aspects of the physical that which *do not* behave as one expects and then studying this unpredicted behavior. Then, with colleagues who have also studied this behavior, too, debating the meaning and significance of this aspect of nature. The result is a never ending, but an ever-deepening explanation of our experiences with the physical world.

Together with my colleagues, I am indebted to the pioneering work of Lillian McDermott and her colleagues at the University of Washington in Seattle and Fred Goldberg and his colleagues at San Diego State University on student conceptions concerning the nature of light and images. Of fundamental importance to the thinking behind this unit are the influences of Jean Piaget and Ernst von Glasersfeld.

Special Acknowledgement

The underlying strategy in these investigations is derived from the work of Dr. James Minstrell, an educational consultant with Facet Innovations, Inc. from Seattle, WA and retired physics teacher from Mercer Island High School. Understandings about student learning and conceptual change gained from my experiences working with Jim Minstrell and his approach have been applied to generate this and the other materials in the *Doing Physics* series.

There have been two other major sources of inspiration for this particular set of activities. One source is colleagues, the most important of which is Dr. Willy Smith who in the early years worked with me on these materials teaching workshops for teachers and students. The other important source, possibly the most important, is the students who have studied these materials through the various versions. Listening carefully to them explaining to me and to each other their understanding of the phenomena. What they said played a large role in which activities remain, which were discarded, and what changes were made to those that remain. I am deeply grateful to all of these students.

A few words before we start…

Few of us manage from day to day to get by without making use of our ability to see in some way. All of us, at one time or another, have described what we have seen with the aid of a lens. To do this, we have used words we understand to be common in everyday language. Do all who hear us think the same meanings as we do when we speak or write the words? We are going to find out.

One of the purposes of education is to get people in the habit of "going further;" asking and attempting to answer questions as best they can in ways that make sense, honing their sense-making skills. We are going to try to cultivate these habits-of-mind in this course.

In science we try to confine our questions and answers to those about phenomena that we can all experience in some reproducible fashion. The end result of this "scientific" effort is a sort of "story" which explains our experiences and enables us to predict the details of future experiences in some satisfactory and useful fashion. In science these explanatory "stories" are often called explanatory models and are the basis of more formally worked out theories that can eventually be described in mathematical form. In constructing these stories we sometimes have to reconsider the meaning of words we use. For such reconsidered words, we have to work out refinements of their meaning with others around us.

So you should think of these activities on light as an exploration not only of light, images and lenses, but an exploration of the meanings of the words we use to describe these things as well. We will be faced with the words used by others to describe light. We have the task of deciding to the best of our ability what they might mean by those words they use to describe light and lenses. Hence, we are not looking for THE definition of such words as focus, image, focal point, etc. by trying to match or guess what some authority says. Instead, as members of our "community" of classmates, we are going to generate our *own* description of what we mean by the use of such terms that we can take-as-shared amongst ourselves as a class. We will base these descriptions on the experiences we have with the lenses, images and pinholes in class and lab.

One of the first differences between this science course and just about all the others you have encountered is in the expression above: "*…we are not … trying to match or guess what some authority says.*" Most typical science instruction is about transmitting to you the "right" answers, "what <u>really</u> is happening," or the "truth" which really smart, very intelligent scientists have figured out for us. This transmission of "knowledge" is usually accomplished by telling it to you (via lectures and text) and then showing you this "truth" in lab. Unfortunately, usually very little of this knowledge, understanding of the phenomena, is ever actually transmitted in any meaningful way in typical science instruction.[1]

In this course not only do these "right answers" not exist *in the sense normally intended in science instruction*, but those "*really smart, very intelligent scientists*" cannot actually determine them for us in any meaningful way. (Actually, this "really smart, very intelligent" idea about scientists in relation to the rest of society is open to question, too.) Only *we* can actually develop our *own* understanding for *ourselves*. While later on we will be in a position to compare our understandings with others, <u>there is *no authority* on the model that *we* will generate but *us*</u>.

The "game" of the farmer and the seeds that we played earlier is intended to illustrate this notion of the nature of knowledge that we will be using in this course. At the end of this little series of activities we will "see" where our knowledge comes from and what are our sources of certainty about this knowledge.

Since the notion of knowledge we will be using in the workshop does not include the notion that it can be "true" in the traditional sense, it must be pointed out that in making use of this view, the "truth," certainty, or correctness of the view itself is *not* being advocated. You are *not* required to accept or believe this view of knowledge or the explanations of the phenomena that we end up developing in class. What you believe for yourself is *your right* and *your*

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[1] There is a large body of research to support this claim. An 8,400 entry bibliography of this literature can be found on-line at: http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html.

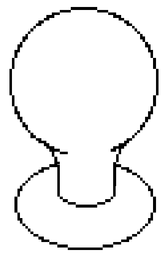
responsibility. *Only you* can determine what to believe for yourself. What is being asked of you in this course is "to try on" this view of knowledge used in the course "for size." In this way you can come to some understanding of it. With that understanding you will be in a position to make use of the view as you see fit.

So, what would exams be about? Generally the definitions and explanations that we develop, test and then agree upon are substantially different in some way than most people's ideas about light when they start (everyday views). Hence, by the time we finish today, we will have at least two different views or sets of definitions concerning terms describing light, 1) the ideas you have as you start the workshop and 2) the ideas we develop during the unit. If one is asked a question about some situation involving light, answers given from these two different views may be very different. If you actually understand each of the two views, then you could give or choose answers (in the case of multiple-choice) consistent with either view. Generally if there were an exam, the questions would be ones for which the two views result in different answers. In such exams, answers consistent with the new explanatory models or ideas we develop as a group will be the ones that would receive credit. Answers consistent with views of the phenomena we had as we entered the workshop would be the ones that do not earn credit. Each set of answers is appropriate in its own context. So, *the exams are not about right and wrong answers*. <u>Long experience with this sort of exam indicates that those who have not participated in the development of the class' definitions generally do not do very well.</u>

In courses using the approach we are describing, it is in the students' best interest to explore this view of knowledge and participate in the process as suggested in the materials and by your instructor. Again, this is not because these views of knowledge or explanations of the phenomena are "true" or "right" or because anyone is insisting that students believe them, but because students will be more successful in the course if they actively "play along" with what we are trying to do. This consists of examining their own ideas and those of their classmates, comparing these with the actual behavior of the phenomena, and then participating in the process of generating new ideas which fit the phenomena better when flaws are found in existing ideas. Sitting back and waiting until the class decides is likely to end in a poor grade in such courses and will result in the course being boring and frustrating. On the other hand, sitting up and participating in the process, being actively curious and communicative can result in a good grade in the course and an overall pleasant experience.

Sincerely,
Dr. Dykstra

Activity 1.0: Light as Rays?
How Might We Represent Light Rays Coming from the Bulb in a Diagram?



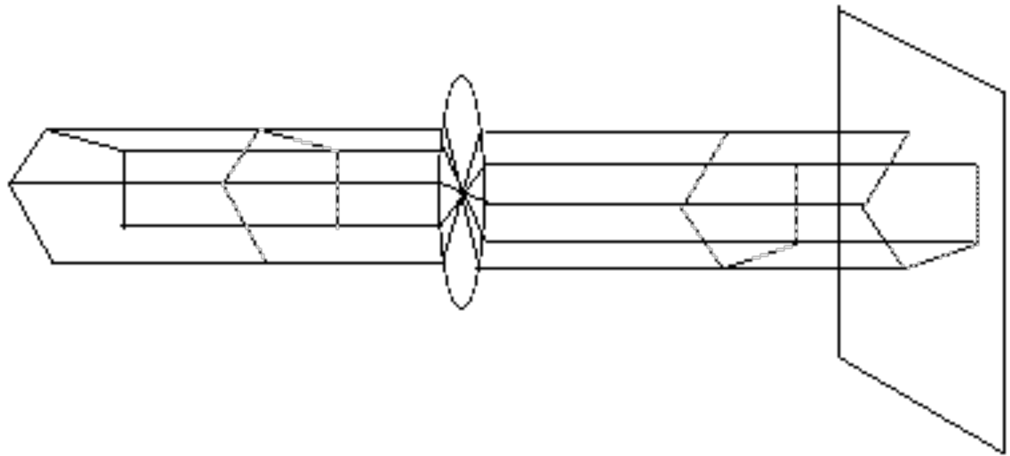
Look at the light bulb your instructor has turned on in the front of the room. Consider how you might represent light coming from the bulb as rays. Draw the rays in on the diagram above. In the space below, describe what aspects of the light rays your diagram is attempting to represent.

To represent a much dimmer bulb, what changes should we make in the diagram above? Give your answer in the space below.

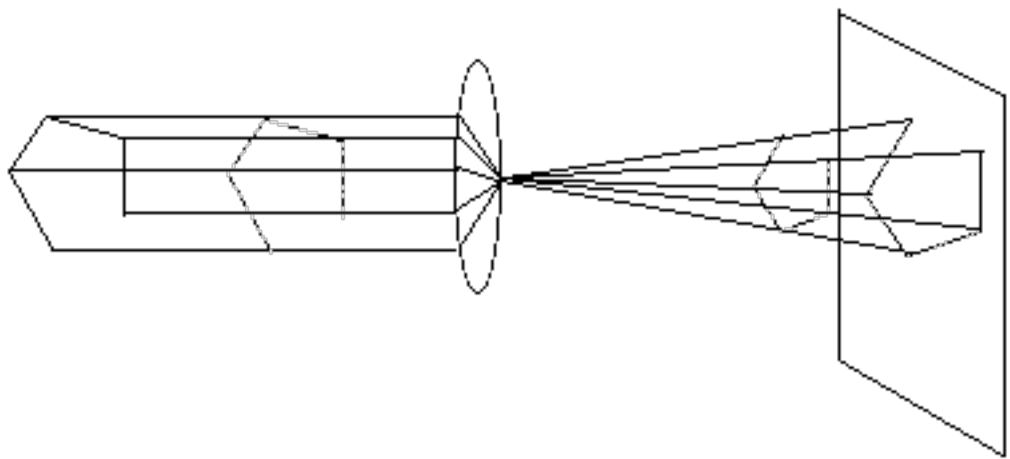
Having listened to and participated in discussion in class, what changes would you make to your answers above? Use the back of this sheet if you need it.

ACTIVITY 1.1: *WHICH MAKES THE MOST SENSE TO YOU AT THIS POINT IN TIME AND WHY?*
In the past students have proposed the following 'models' to explain how the image comes to be on the screen and in the orientation in which we find it. Study each and decide if one of them makes most sense to you. If you find one, circle its title and then, on the next page, explain why it makes sense to you in the space provided. If none of these seems appropriate, carefully draw your own in the space provided on the next page. Do not attempt to test your decision by experimenting with the apparatus at this time.

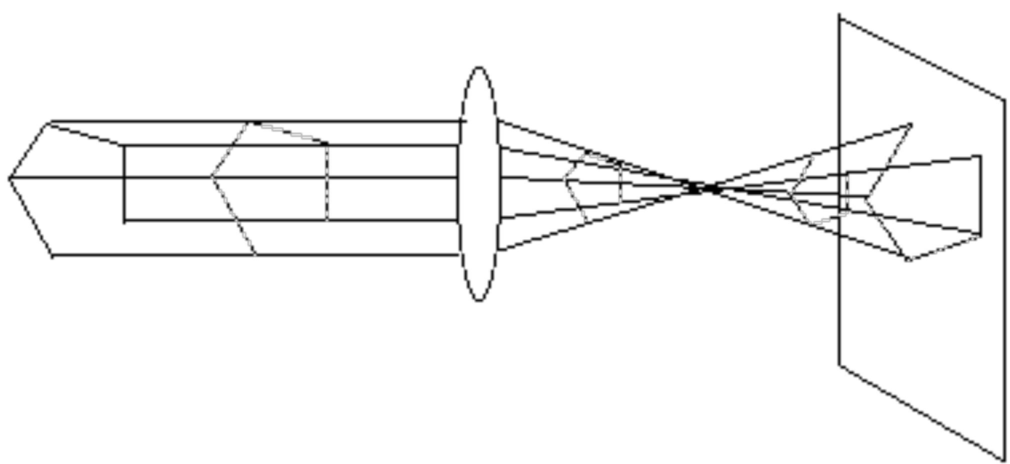
A. "Image inverted in Lens" Model



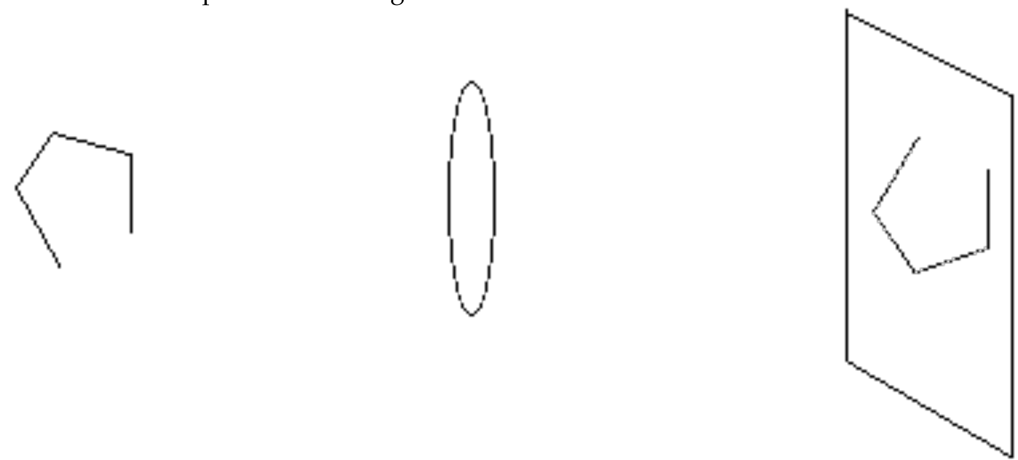
B. "Image inverted by projection from Lens" Model



C. "Image inverted through a point behind the Lens" Model



If none of the models on the previous page satisfy you, then carefully sketch with a straight edge what you think the rays of light do through the lens to result in the image on the screen below. Give your model a name and put it on the diagram.

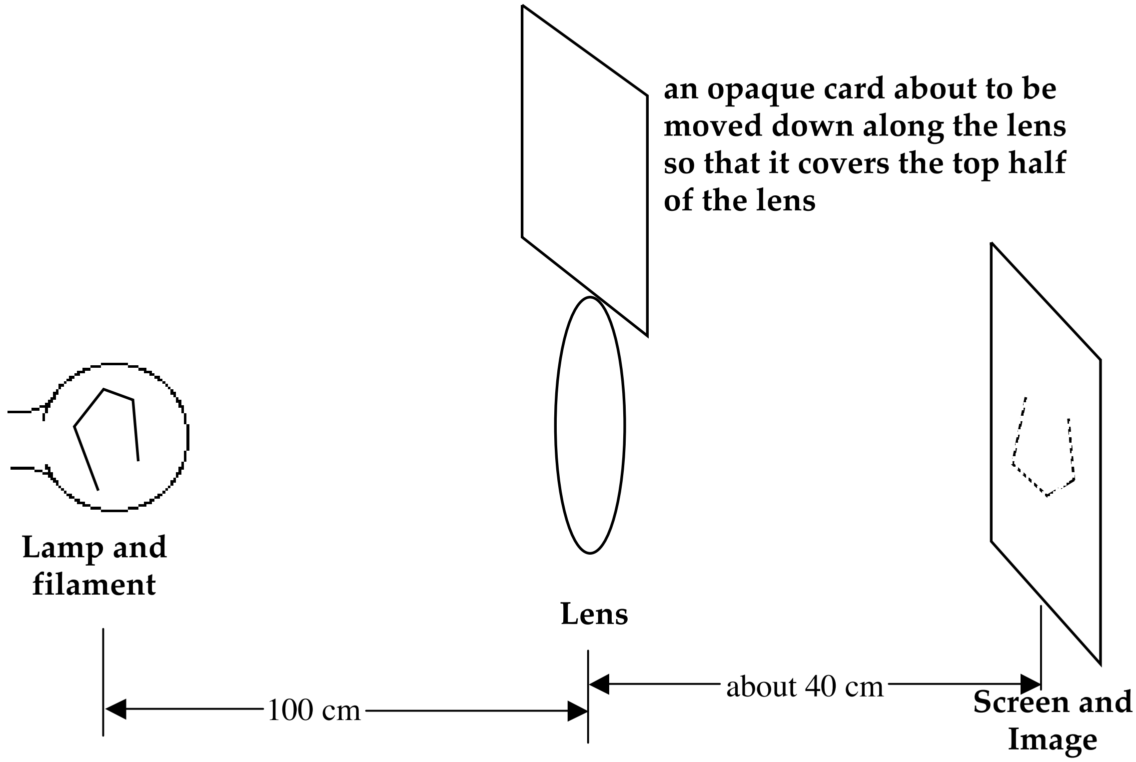


AT THIS POINT WE ARE ONLY SPECULATING. **<u>UNDER NO CIRCUMSTANCES</u> SHOULD YOU OR YOUR GROUP BEGIN TO "TEST" YOUR CHOICES.** TESTS OF THESE MODELS WILL BE CONDUCTED IN DUE TIME.

1. YOUR IDEAS: In the space below, jot down your reasons for your choice. Use the appropriate diagram to support your choice. You may draw on the diagram to illustrate your ideas.

2. THE GROUP'S IDEAS: Share your ideas with your group and see if the group can come to a consensus. Write the group's consensus, if there is one, below. Things that you have observed so far should be considered as you discuss this question. The group's choice should be supported by observations which you should indicate in your notes on the opposite side of this sheet.

ACTIVITY 1.2: *WHAT DO YOU THINK WOULD HAPPEN TO THE IMAGE ON THE SCREEN WHEN THE TOP HALF OF THE LENS IS COVERED?*

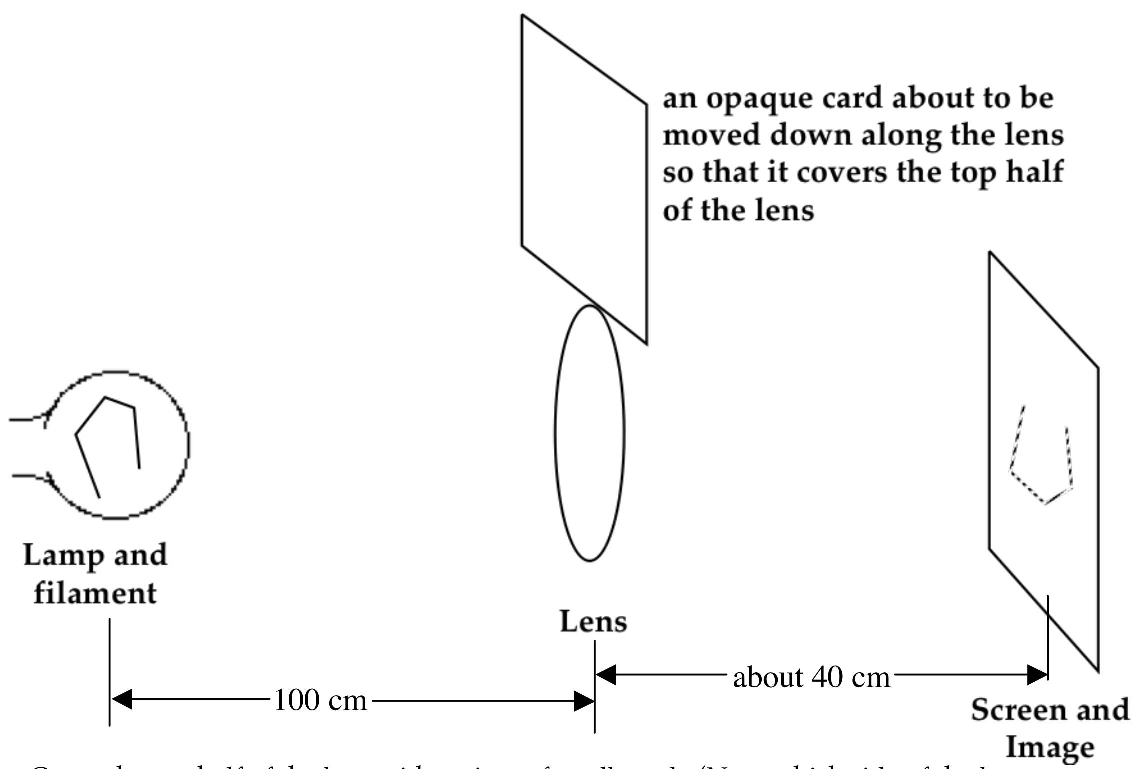


REMEMBER: It is critical that you not test to see what actually happens until the "Making Observations" step of the activity. The first two steps, "What do you think?" and "What does the rest of your group think?" are not about getting the "right answer". These first two vital steps are about getting your own ideas out in the open and examining them. Looking to see what actually happens before you are directed to will seriously damage the valuable results which can come from these first two steps, both for you personally and for the members of your group. Please do not try to see what happens until it is time.

1. **WHAT DO YOU THINK?:** Jot down your personal prediction and, as clearly as you can, describe your reasoning as to why your prediction seems reasonable to you. Sketch light rays using a straight edge on the diagram above to illustrate your ideas. You will find it useful to consider the following question as you consider the main question for this activity.
   Do you think it would matter which side of the lens you cover?

2. **WHAT DOES THE REST OF YOUR GROUP THINK?:** Share your ideas with your lab group. Try to come to a group consensus about what will happen and why the prediction seems reasonable. Describe the group's conclusion in the space below. Add to the diagram on the previous page to explain the group's ideas, if anything new is decided upon.

3. **MAKING OBSERVATIONS:** When the group is pretty sure of their ideas: <u>Make sure your lens is 100 cm from the lamp filament. Then starting with your screen 40 cm from the lens, move the screen closer or further from the lens to get the sharpest possible image. Record what happens as you try the following.</u>



a. Cover the top half of the lens with a piece of cardboard. (Note which side of the lens you covered.) Put your observations in words below.

b. Now cover the top half of the <u>other</u> side of the lens. *Does this make any difference in what happens?*

c. *Does it matter if you covered the bottom half or the left or right halves of the lens?* Try it and record your observations.

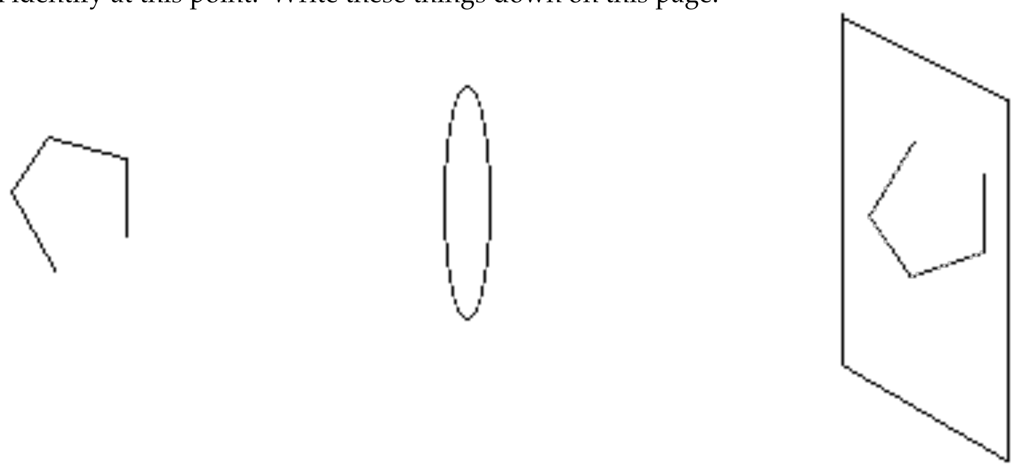
d. *How much of the lens can you cover and still see the image? What do you see on the screen as you cover more and more of the lens?*

4. MAKING SENSE: Compare your observations with your prediction, the predictions of your partners, and the predictions suggested by the explanatory ray diagram models from Activity 1.6. *How does the outcome compare with the predictions? Is this what you thought you would see? If not, what specifically is different than you thought would happen?*

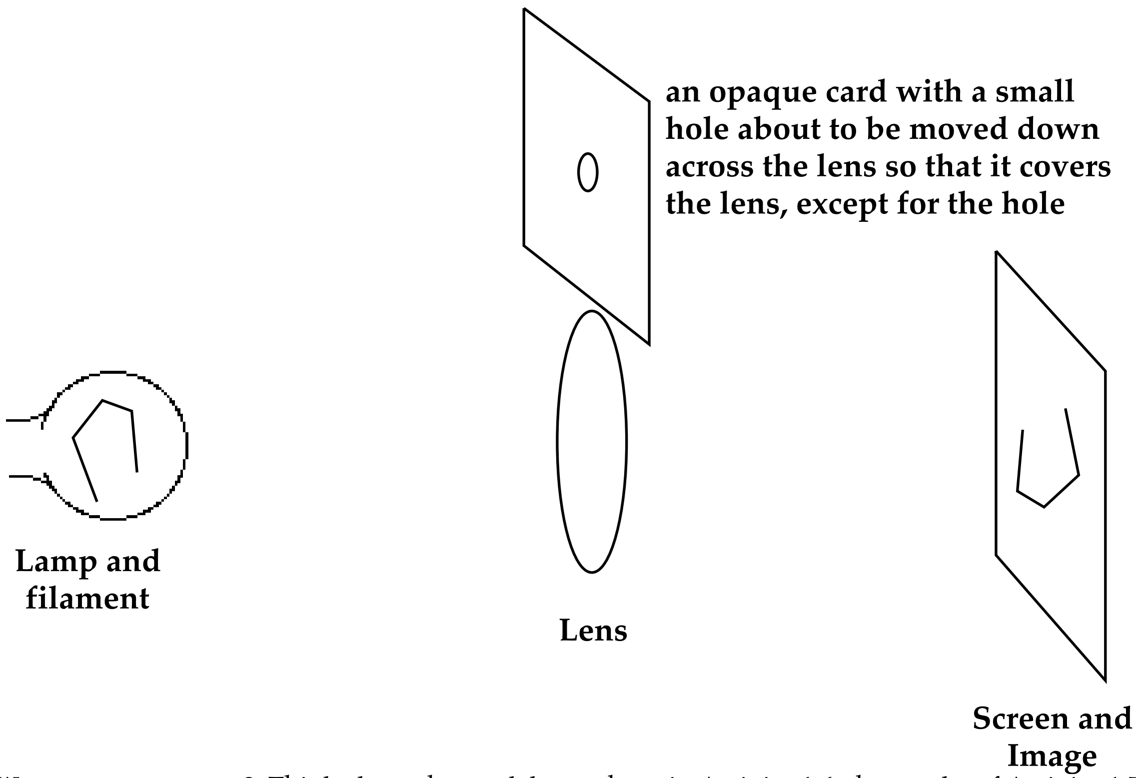
Discuss any discrepancies with your group. *Can the group come up with any ideas which might explain the surprising aspects of what you saw?* If so, write the group's conclusions in the space below. If not, write down the group's thoughts about what is unclear so far.

CONSIDERING THE MODELS IN ACTIVITY 1.1: *Which of the models are consistent with or can explain what you have just seen with the card covering part of the lens? …or do any of them seem to be appropriate?* Discuss with your group and write the group's explanation below. *Can you come up with something better?* Use the diagram below to explain your ideas. <u>Use a straight edge to draw the rays</u>.

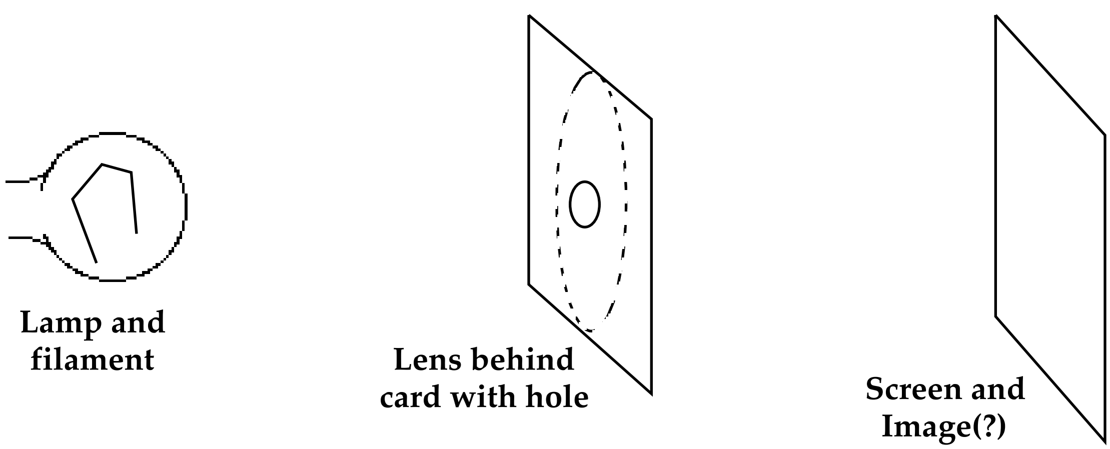
The goal in this one activity is not to come up with a final answer, once and for all. What we want to do is to come up with something, if we can, that at least accounts for what we have seen so far and that is consistent with our previous experiences. There are more activities for you to carry out in this lab session which may lead to further refinements later. But, it is important for you to try to identify now some features which such a model might have and some of the specific "unknowns" or problems that your group can identify at this point. Write these things down on this page.



ACTIVITY 1.3: *WHAT DO YOU THINK WOULD HAPPEN TO THE IMAGE ON THE SCREEN WHEN THE LENS IS COVERED UP, ALL BUT A SMALL HOLE?*



1. **WHAT DO YOU THINK?:** Think about the model you chose in Activity 1.6, the results of Activity 1.7 and what you decided about the models from Activity 1.6 based on the results of Activity 1.7. In the space below, jot down your personal prediction and, as clearly as you can, describe your reasoning as to why your prediction seems reasonable to you. Use the model that you think makes the most sense (either one from Activity 1.6 or one that you and your group have devised that is better) to make a drawing that helps explain your ideas. Sketch light rays using a straight edge on the diagram below to illustrate your ideas.



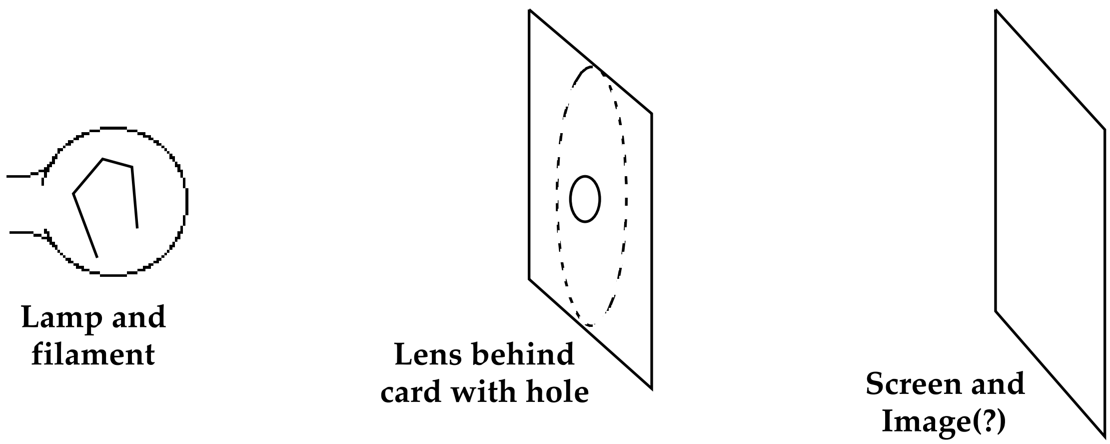
Continue with your ideas on the next page.

You will find it useful to consider the following questions as you consider the main question for this activity.
Might the image get smaller or larger when you cover up the lens, all but a small hole?

Do you think it would matter which side of the lens this card is on?

Do you think it would make any difference where on the lens the hole is placed?

2. **WHAT DOES THE REST OF YOUR GROUP THINK?:** Share your ideas with your lab group. Try to come to a group consensus about what will happen and why the prediction seems reasonable. Describe the group's conclusion in the space below. Again, use the diagram to explain your ideas.



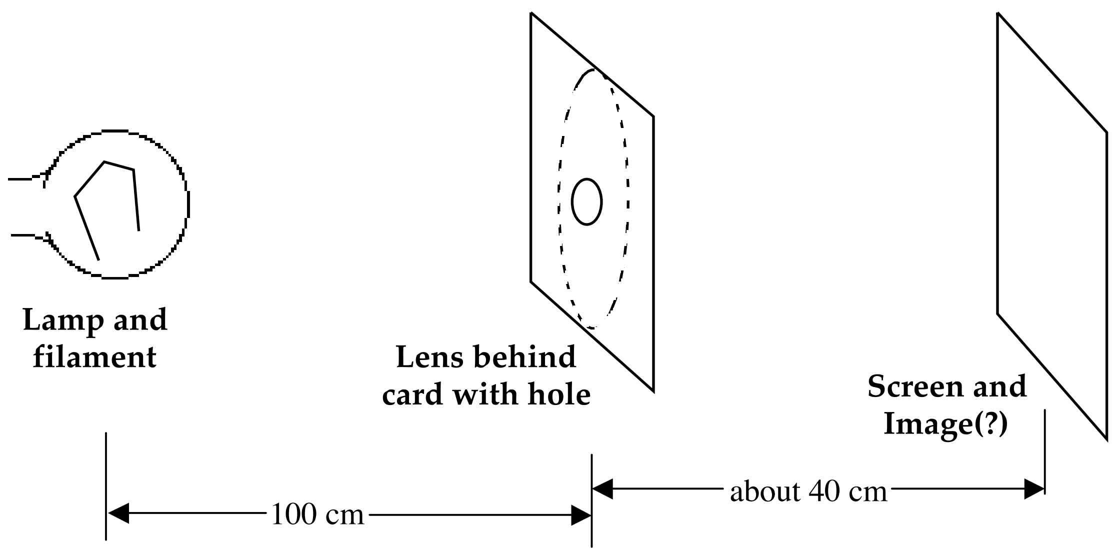
Might the image get smaller or larger when you cover up the lens, all but a small hole?

Do you think it would matter which side of the lens this card is on?

Do you think it would make any difference where on the lens the hole is placed?

3. **MAKING OBSERVATIONS:** When the group is pretty sure of their ideas, adjust your apparatus to get the <u>sharpest</u> image and try these things.

a. Hold the card with the small hole near the center of the lens in front of the lens. Record what happens. Illustrate what you think is happening by sketching rays and what you see on the screen in the diagram below. *Does the image get smaller?*



b. Put the card on the <u>other</u> side of the lens with the hole near the center. Record what happens. *Does this make any difference in what happens?*

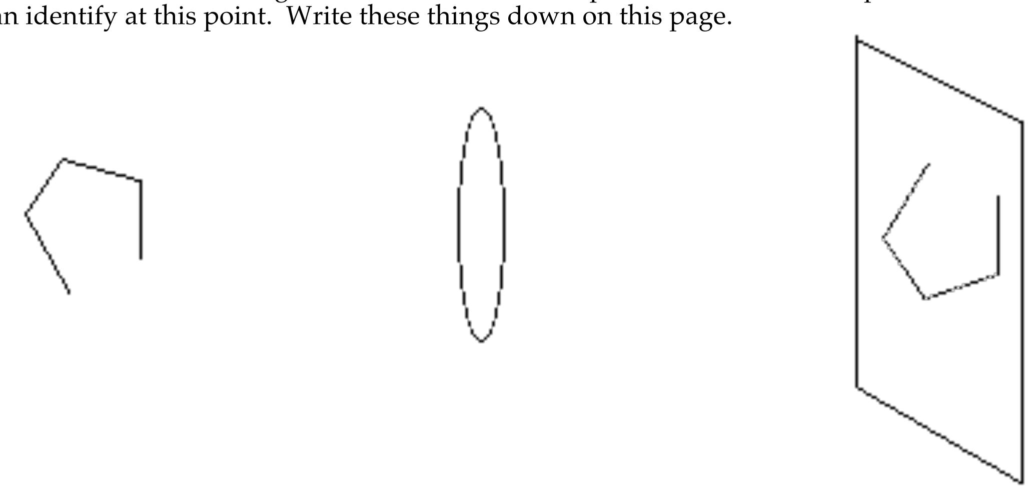
c. *Does the image size, shape, or location change as you move the hole to different parts of the lens?*

4. **MAKING SENSE:** Compare your observations with your predictions. *Is this what you thought you would see? If not, what is different than you thought would happen?*

Discuss any discrepancies with your group. *Can the group come up with any ideas which might explain the surprising aspects of what you saw?* If so, write the group's conclusions in the space below. If not, write down the group's thoughts about what is unclear so far.

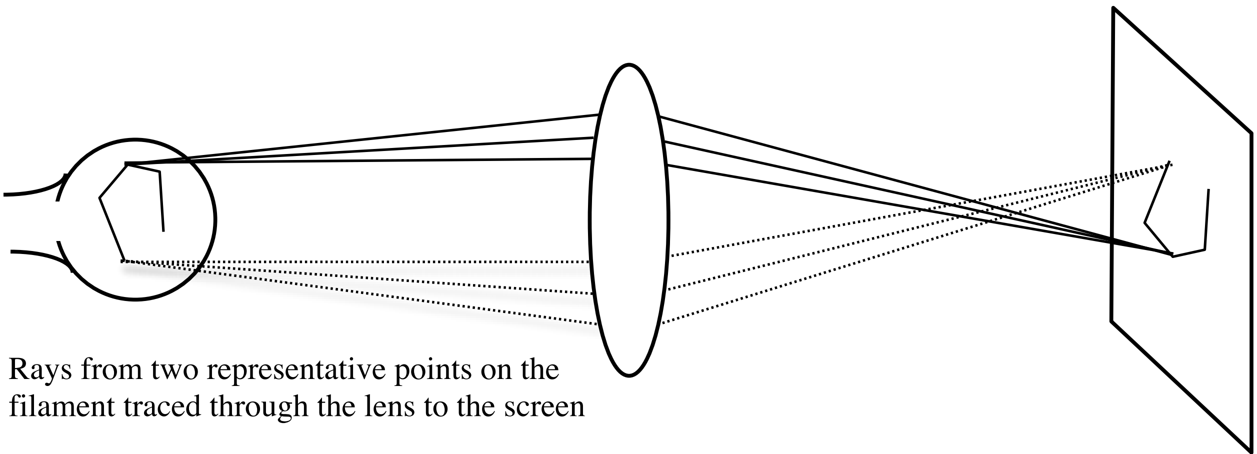
CONSIDERING THE MODELS IN ACTIVITY 1.1: *Which of the models are consistent with or can explain what you have just seen with the card covering part of the lens? …or do any of them seem to be appropriate?* Discuss with your group and write the group's explanation below. *Can you come up with something better?* Use the diagram below to explain your ideas. <u>Use a straight edge to draw the rays</u>.

The goal in this one activity is not to come up with a final answer, once and for all. What we want to do is to come up with something, if we can, that at least accounts for what we have seen so far and that is consistent with our previous experiences. There are more activities for you to carry out in this lab session which may lead to further refinements later. But, it is important for you to try to identify now some features which such a model might have and some of the specific "unknowns" or problems that your group can identify at this point. Write these things down on this page.

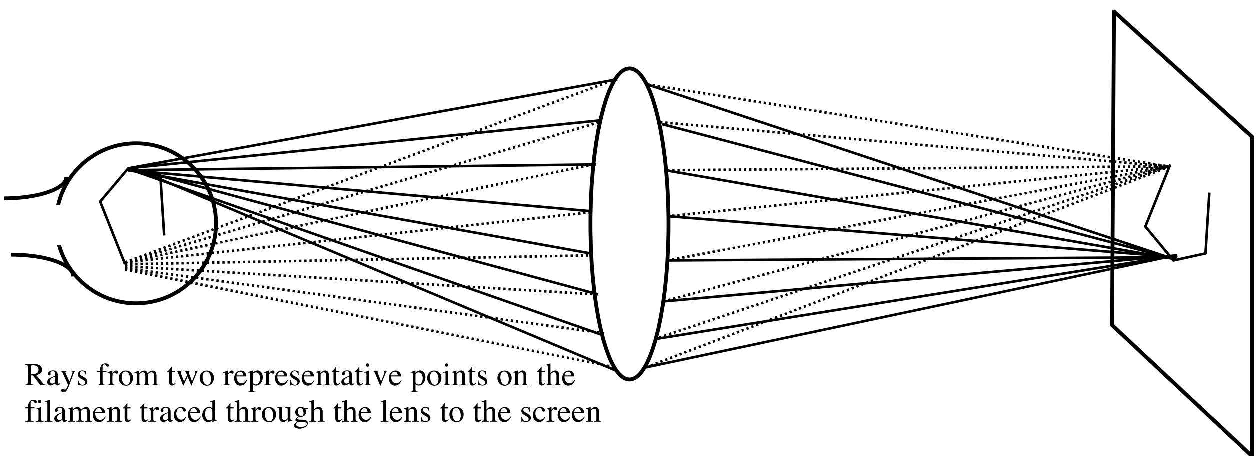


DRAWING A CONCLUSION:

ACTIVITY 1.4: ***DOES IT SEEM THAT THE LIGHT FROM ONE PART OF THE FILAMENT GOES THROUGH ONLY ONE PARTICULAR PART OF THE LENS (SOMETHING LIKE THE DIAGRAM JUST BELOW) OR…***



DOES LIGHT FROM ALL PARTS OF THE FILAMENT GO THROUGH ALL PARTS OF THE LENS (SOMETHING LIKE THE DIAGRAM BELOW)?

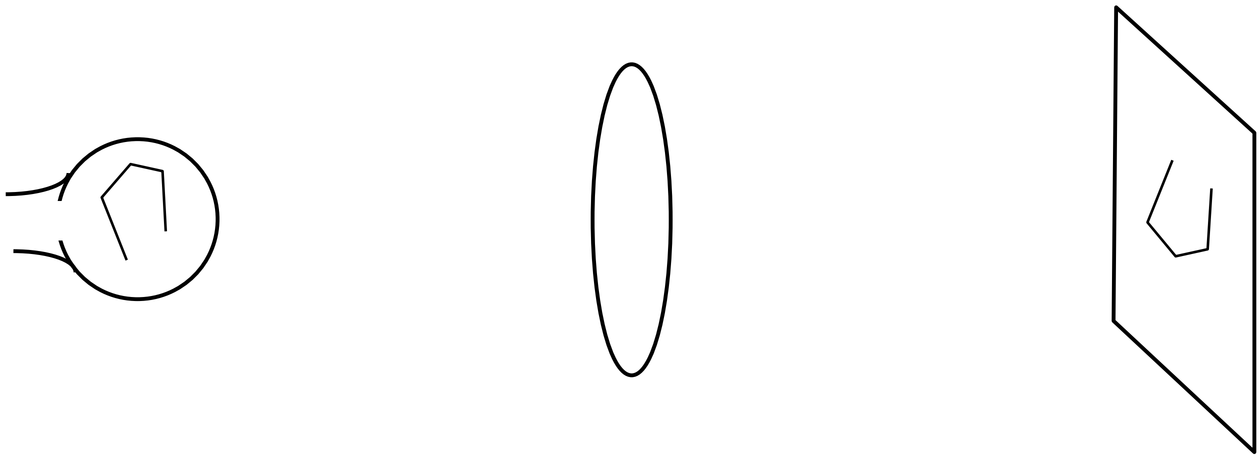


Consider these two possibilities which have been suggested by your classmates both this semester and in previous semesters. Also, look back at your conclusions so far from the previous activities and consider the results.

Which one do you think makes the most sense in the light of what you have observed so far?

On the next page jot down your ideas on this question. Include reasons behind your answers to this question and cite things you saw in lab and in demonstrations so far to support your choice. Use the appropriate diagram above to support your choice. Draw on the diagram to illustrate your ideas.

If neither of these makes the most sense to you, then carefully make a drawing that makes more sense to you. Just draw rays on the diagram below to illustrate your alternative.

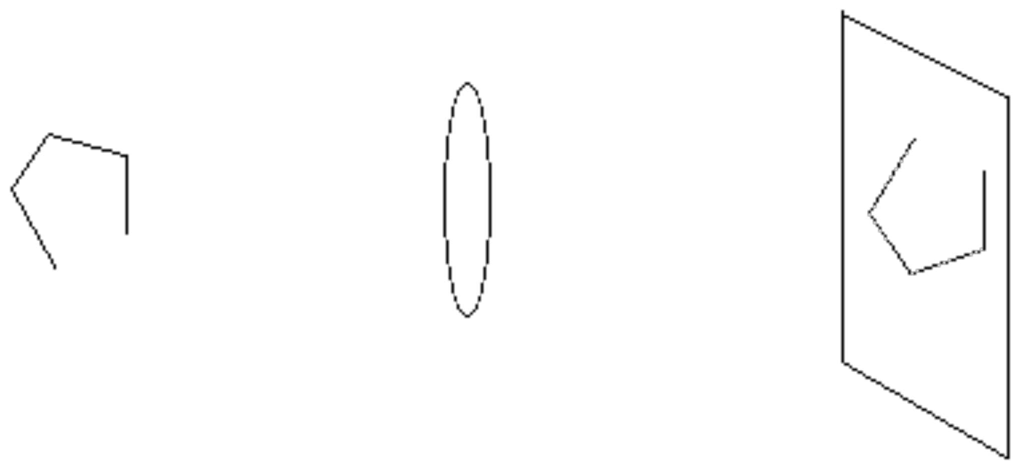


1. **YOUR IDEAS:** In this space put your reasons for the choice you made on the previous page.

2. **THE GROUP'S IDEAS:** Share your ideas with your group and see if the group can come to a consensus. Write the group's consensus below. Things that you have observed in lab should be considered as you discuss this question. The group's choice should be supported by observations from lab which you should indicate in your notes below.

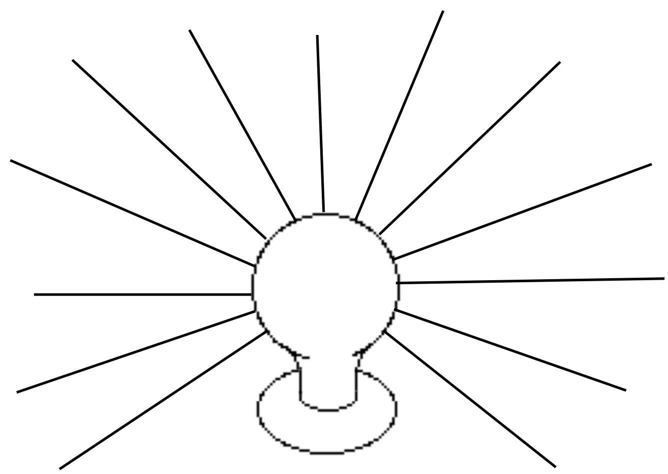
CONSIDERING THE MODELS IN ACTIVITY 1.1: *Which of the models are consistent with or can explain what you have just seen with the card covering part of the lens? …or do any of them seem to be appropriate?* Discuss with your group and write the group's explanation below. *Can you come up with something better?* Use the diagram below to explain your ideas. Use a straight edge to draw the rays.

The goal in this one activity is still not to come up with a final answer, once and for all. What we want to do is to come up with something, if we can, that at least accounts for what we have seen so far and that is consistent with our previous experiences. There are more activities for you to carry out in this lab session which may lead to further refinements later. But, it is important for you to try to identify now some features which such a model might have and some of the specific "unknowns" or problems that your group can identify at this point. Write these things down on this page.



Images Activity 2.0
NOW How Might We Represent Light Rays Coming from the Bulb in a Diagram?

(Examining the "Mr. Sunshine" Model of Light Rays)



At the beginning of this unit on light we drew rays of light from the bulb. Many drew something like the diagram above. We have looked at the behavior of light in images from lenses and seen what light rays must explain if they are to be used explain phenomena involving light. Given what you have seen so far, consider whether the diagram above is sufficient to represent light rays from the bulb. *In other words is the diagram above okay or should it be changed somehow to better represent how light rays must behave to explain what we have seen so far in lab and demonstrations?* After explaining your ideas in words, draw on the diagram to illustrate what you mean. Cite observations you made in lab to support your conclusions. Explain how they support your conclusions. Use space on the back, if you need to.

When you have gotten your ideas on paper, share them with the people around you and see if you can come to some consensus. If you decide to change your ideas, record the new ones, why they seem reasonable to you, what made you change your ideas and why.

Communication
Where is the meaning? Is it in the words of the sentences? Where does it come from?

Sentence:	What it means:
How about a nice Hawaiian Punch?	
She said she wouldn't run until the drug question was settled.	
The top group advanced to the front.	
He walked to the bank and stepped in. He immediately began to shiver.	
They were starting to take the sheets in when it began to rain.	
The teacher needed the right footing to get started.	
As the wind picked up the bark started flying, which made April uncomfortable.	
Said in 1942: The Italian navigator has landed in the new world.	
The police were called to an apartment on the second floor. Entering, they found broken glass, water all over, a cat on the couch, and Agnes and Bert on the floor.	Who were Agnes and Bert?
Andy is riding his bike through the park with a group of others and someone up ahead yells 'Duck!'	What should Andy do?

"Waiter, this coffee tastes like mud!" *"That's odd, it was ground just this morning."*

What do you think? Do sentences **carry** meaning?

What are these people talking about??
Fill in a meaning that makes sense.

Speaker	Said	Meaning?
John	Dana succeeded in putting a quarter in a parking meter today without being picked up.	
Anne	Did you take him to the music store?	
John	No, to the shoe store	
Anne	What for?	
John	I got some new laces for my shoes.	
Anne	Your loafers need to be replaced.	

Some of the details they might have been thinking:

Who	Spoken	Portions of intended meanings
John	Dana succeeded in putting a quarter in a parking meter today without being picked up.	This afternoon as I was bringing Dana, our four year old son, home from the nursery school, he succeeded in reaching high enough to put a quarter in a parking meter when we parked in a meter parking zone, whereas before he has always had to be picked up to reach that high.
Anne	Did you take him to the music store?	Since he put a quarter in a meter that means you stopped while he was with you. I know that you stopped at the music store either on the way to get him or on the way back. Was it on the way back, so that he was with you, or did you stop there on the way to get him and somewhere else on the way back? If somewhere else, where?
John	No, to the shoe store	No, I stopped at the music store on the way to get him and stopped at the shoe store on the way home when he was with me.
Anne	What for?	I know of one reason why you might have stopped at the shoe store. Why did you in fact?
John	I got some new laces for my shoes.	As you will remember I broke a shoe lace on my brown oxfords the other day so I stopped to get some new laces.
Anne	Your loafers need to be replaced.	I was thinking of something else you could have gotten. You could have bought shoes to replace your black loafers which are getting worn out. You'd better get that taken care of pretty soon.

Questions for discussion: Implications on the job of a teacher:

Can a teacher transmit meanings (such as her own knowledge) to students?

Can a teacher be sure that her students have the meanings that she intended?

What is the main task of learners?

Considering the task of the learners, what kinds of strategies might make a difference in a teacher's effectiveness?

Does this statement make sense?

Heinz von Foerster had a knack for statements that sounded paradoxical. In fact, they made a lot of sense when they were unpacked. At the very beginning of our joint recollections in a book we published together a few years ago, he said for example: “It’s the listener, not the speaker, who determines the meaning of an utterance.”

(Written by Ernst von Glasersfeld. To be read by Josef Mitterer at the Memorial Meeting for Heinz von Foerster, Vienna, November 2003)

The Constructivist View of Communication

Heinz von Foerster had a knack for statements that sounded paradoxical. In fact, they made a lot of sense when they were unpacked. At the very beginning of our joint recollections in "Wie wir uns erfinden", a book we published together a few years ago, he said for example: "It's the listener, not the speaker, who determines the meaning of an utterance."

Taken literally, this seems to demolish any possibility of linguistic communication. The usual assumption is that the speaker has something to say, formulates it in words, and utters them as a piece of language; and then it's the listener's task to UNDERSTAND what the speaker intended. To say that it is the listener, who determines the meaning of the utterance, seems to eliminate the speaker.

Heinz had no intention of doing this. What he meant was: given the words a speaker has used, the listener can interpret the utterance only in terms of the meaning he, the listener, ascribes to these words.

This, of course, raises the question of how any listener – or speaker – has come to ascribe meanings to the sounds we call "words".

To answer this question is not nearly as easy as you might think. Meaning has been a topic of erudite writers ever since the Greek philosophers; but they usually presented it as something that "exists" ready-made apart from the users, rather than something that has to be slowly built up by each new member of a linguistic community. The condition, that meaning must be MADE before it can be used, was not explicitly shown until Claude Shannon published his Theory of Communication in 1949.

Shannon's "Mathematical Theory" is a technical document covering engineering problems such as the design and capacity of communication channels, the interference of noise, and the use of redundancy in interpretation. Right at the beginning, however, Shannon makes a fundamental point that has enormous consequences for the understanding of how LINGUISTIC communication functions. His fundamental insight was that MEANING does not travel. In order to transmit something from one place to another, it must have the form of a "signal". A signal is something that can travel through space. It may be a change of energy in an electric wire or electromagnetic waves, modulation of sounds, marks on a piece of paper, anything, in fact, that can be sent from one place to another. To such signals messages can be related by means of a code. This is a sheet with two columns, one of which lists signals or combinations of signals, the other what the signals are to stand for. In the case of telegraphy, a code was designed in 1837 by a Mr. Morse.

If you wanted to be a telegraphist, you had to learn the Morse code. This was not particularly difficult because it had been internationally agreed on and was readily available all over the world. Side by side there were two columns in the Morse code. On the left were the letters of the alphabet, on the right dots or dashes or combinations of the two. Once you had acquired the code, you could translate the words of a message into sequences of dots and dashes and send them to anyone who was in possession of the code.

You may know, for instance, that in the Morse code a single impulse or dot stands for the letter "E". But it is not the dot that tells you this – you know it only because you know that much of the code.

Norbert Wiener used a very simple example to illustrate communication and the role of the widely abused term "information". Flower shops, he said, can send flowers anywhere in the world, without sending the flowers. They send them by cable. This was long before e-mail, and telegraphy was the way to do it. Flower shops had an international code that listed a variety of flowers and good wishes in the left column and a number, say between 1 and 100, in the right column. If you wanted to send a dozen red roses to a friend in the United States, the shop here in Vienna would merely cable the address and the code number corresponding to your choice of flowers. The INFORMATION transmitted, therefore, was simply an instruction to select a specific word or phrase from the right-hand side of the flower code.

The Morse code, of course, made it possible to send words. But what the words contained in a message are intended to MEAN, is not indicated by this code or any other system of communication. The receiver, as Heinz said, has to determine the meaning for him- or herself.

It is usually taken for granted that we can unravel the meaning of words, if we are speakers of the language that is being used. But the question of how we acquire the skill of doing this has not yet been satisfactorily answered. Chomsky's contention that the human animal has an innate language organ does not apply to the generation of meaning but only to syntax – and there it merely shifts the problem into the area of evolutionary hypotheses that have little if any hope of ever being confirmed.

If we look a little more closely at HOW a listener may determine what meaning to attribute to something that was said, we can list at least four things that seem indispensable:

1) Sounds must be recognized as sound-images of words that evoke associations.
2) These associations are, in fact, re-presentations of elements of past experience.
3) These remembered elements of experience constitute the material for POSSIBLE meanings of the utterance.
4) Which of these possibilities the listener accepts, depends on the context in the widest sense including the listener's familiarity with the speaker.

This inevitably raises the question: How the sound-images of words were linked to elements of experience in the first place. Children are not handed a ready-made code that lists the word-meanings and the syntactic rules of their language.

In what follows I shall briefly describe a new pragmatic approach to language acquisition, developed by Michael Tomasello at the Max Planck Institute for Evolutionary Anthropology at Leipzig. This approach is not based on any particular linguistic theory but focuses on the question of how children learn to use language in practice.

Norbert Wiener tentatively suggested the fundamental feature of the pragmatic approach long ago when he discussed communication in different species of animals and with strange people.

> "Suppose I find myself in the woods with an intelligent savage who cannot speak my language and whose language I cannot speak. Even without any sign language common to the two of us, I can learn a great deal from him. All I need to do is to be alert to those moments when he shows the signs of emotion or interest. I then cast my eyes around, perhaps paying special attention to the direction of his glance, and fix in my memory what I see or hear. It will not be long before I discover the things which seem important to him, not because he has communicated them to me by language, but because I myself have observed them." (1948, p.157)

In his book "Constructing a Language", Tomasello explains that it is "the ability to share attention" that furnishes the basis for the inception of meaning. It is the sort of claim that seems obvious the moment it has been stated. But because the whole problem of attention had for a long time been ignored by psychologists, its role in language acquisition was not acknowledged.

From the constructivist point of view, it is important to stress that it does not matter if the thing I perceive when I follow the direction in which the other is looking is not quite the same as the thing he or she perceives. What DOES matter, in order to link a word to a percept, is that, whenever he or she utters a specific word, I see something that I can consider the repetition of what I saw on similar previous occasions. The crucial feature is the coordination of attention.

Tomasello stresses a second factor that is even more important: "… the ability to understand that other persons have intentional and mental states like one's own" (2003, p.40). He speaks of "intention reading" and this implies, among other things, the desire to anticipate what the other is going to do.

I do not think that "intention reading" is an unwarranted assumption. Many animals behave in ways that suggest it. A scene that I described many years ago in another context may serve as example.

One thing visitors to the famous Yellowstone Park usually want to see is an elk. The elk is a large rather bulky kind of stag with huge, very solid antlers. At mid-day, when most of the tourists are at Yellowstone, the elk is usually resting almost invisible in the middle of a field of high grass. A front of people gingerly approaches, their cameras ready to click. When they come to about thirty meters from the elk, he raises his head as though he were getting up to charge. But he does not have to stand up, let alone charge. He has learned that raising his head and antlers is sufficient to stop the intruders. It works every time they attempt to get closer. If they want a picture of more than just the elk's antlers sticking out above the high grass, they have to buy a postcard at the tourist center.

Why does the elk raise his head? He anticipates that, if he does nothing about it, the people will come closer than he likes. Raising his head is a reliable way to stop them. I am not suggesting that the elk has a concept of intention, but he acts on what experiential sequences have taught him in the past.

Intelligent animals are able to anticipate all sorts of things. Cats patiently keep their eyes on the hole where the mouse disappeared, clearly anticipating that it is the place where the mouse will come out again.

The poodle we once had got bored when I spent too much time at my desk. He would fetch his leash and shake it at the side of my chair. Knowing that I always put him on the leash when we went out, he anticipated that I would understand his suggestion. If I did not react, he would drop the leash on the floor and walk off in a way that left no doubt about what he thought of me.

In fact, all learning entails a form of anticipation. As Humberto Maturana expressed it:

> "A living system, due to its circular organization, is an inductive system and functions always in a predictive manner: what happened once will occur again. Its organization (genetic and otherwise) is conservative and repeats only that which works." (1970)

Even Skinner's behaviorist notion of reinforcement implicitly requires the organism to anticipate that what had a pleasant result in the past will have a pleasant result in future, and that what had unpleasant consequences will have them the next time. The fact that this anticipation probably is not conscious in rats and pigeons – or even in my late poodle – does not stop me from using the anticipatory pattern as a description of their behavior;

because at higher levels of cognitive development it certainly IS conscious and leads to deliberate action.

In his book on the attainment of consciousness (*La prise de conscience,* 1974), Piaget showed two things on the basis of a series of empirical studies carried out by members of his team. First, consciousness appears gradually in children and, second, its attainment in one context does not necessarily entail its presence in others.

Tomasello has made a solid case for the idea that "intention-reading" plays an important role in children's acquisition of word-meaning, that is, of semantics. I now want to suggest that anticipation is a key factor in the development of syntax.

In the first months of their life, infants begin to exploit if-then relations. If a switch is placed under their pillow so that a bell rings every time they turn their head to the left, they will repeat the turn to the left until they get bored with the sound of the bell. In other words, infants behave as though they knew about causal connections. At that age, however, they are only beginning to separate themselves as an entity from the experiential field and it would be absurd to claim that they have already abstracted what philosophers call "knowledge that"; but their behavior indicates that they are able to act on what they might later call "knowledge how". By the time they have lived for four or five years, they are wondering whether it is the wind that moves the branches of trees or the moving branches that cause the wind. Sometime in between they have created the notion that there are agents whose actions can be expected to have certain consequences.

Some of my colleagues will say: Of course they have that kind of notion! But they have it only because, since their infancy, they have been immersed in language. In my view this is putting the cart before the horse. If there were no prior experiential foundation, the meaning of the agent-activity connection and the activity-result connection could not possibly be grasped.

The behavior of cats shows that they associate being fed with an adult of the family and not with a three-year-old. And the behavior of my dear old poodle made it quite clear that he had associated going for a walk with me, and not our daughter, who was his favorite playmate. For all we know, neither cats nor poodles have what we would call language. Nevertheless, their behavior indicates that their experiential world comprises relatively stable elements that are analogous to what we, humans, abstract as concepts and speak of as "agent", "activity", and "result".

Linguists have only fairly recently used more descriptive terms such as "agent" and "patient". The entities these terms designate were included in the large grammatical categories of *subject* and *object*. In linguistics, these terms refer to parts of a sentence and in no way to parts of anyone's experience. Subject, verb, and object are syntactic terms and refer to the structure of sentences, not to the links we have created among the things we perceive and live with. It was a long-standing tradition in linguistics to separate syntax from semantics, as though the two domains had nothing to do with each other. In my view, it was this rigid separation that made it very difficult for linguists to develop a viable theory of language acquisition.

As Tomasello and a few before him noticed, Children do not produce their utterances with the help of grammatical rules. Even adults rarely rely on abstract syntactic rules to guide their speech. They know how they have segmented their experience and the praxis of living has shown them useful ways of linking the segments.

In many cases it is simply the way the connection between experiential elements has actually been made that determines the kind of link between them. Let us assume that your attention is caught by the color red. As such the redness is not confined, has not yet a specific shape in your visual field, and is not a discrete thing. But as you focus on it, you are able to fit the color into the pattern you have learned to call "house". If you were asked to describe what you see, you would most likely say: "there is a red house". You choose the adjectival connection because the color and the thing were produced in a continuous application of attention. If, on the other hand, you recognize in your visual field a pattern that fits your concept of "house" and only then, scanning it more closely, you focus attention on its color, you would most likely say: "the house is red". This syntactic structure clearly expresses that the concept of "house" was brought forth independently of the color that was subsequently attributed to it.

Note that the experiential sequence does not DETERMINE a particular syntactic order or marker, but differences in the experiential sequence are likely to be expressed syntactically in SOME way.

Piaget suggested that the child's organization of space is topological before it acquires the three-dimensional Euclidean structure. I think the development of the conceptual links by means of which we weave the fabric of our experiential world is analogous. Like surfaces in topology, the first links the child establishes between elements of experience are somewhat shapeless and stretchable. Only later, through the practice of communication in interaction with others, do they become more definite and turn into specific syntactic relations.

I see a parallel to this in the way most languages use prepositions. Traditional linguistics did not ascribe a syntactic function to words such as "in", "on", "at", and "by", but treated them as rather insignificant particles. It was my friend and early mentor Silvio Ceccato, who first recognized that prepositions indicate conceptual links between parts of speech just as syntactic markers do. And just as for instance the verb-object relation comprises a number of conceptually different links, so prepositions are as a rule ambiguous in that they indicate not one, but a group of POSSIBLE conceptual relationships.

Take as an example some of the different uses of the English preposition "by":

"A tree by the house",
"A book by Hemingway",
"We came by bicycle",
"We came by the high road",
"We'll be ready by Sunday".

The conceptual links indicated between the two experiential items in these expressions are all different. This multiplicity causes a problem for translators, because the links covered by ONE preposition are rarely quite the same in two languages. Try to translate my five examples into German. Each of them requires a different word in that language: "bei", "von", "mit", "auf" or "über", and "am" respectively. We can roughly characterize the differences by saying "by the house" indicates a spatial location, "by Hemingway" authorship, "by bicycle" a method of locomotion, "by the high road" an itinerary, and "by Sunday" a point in time.

Detailed conceptual analysis may show, as Ceccato believed, that in each group there is an underlying generic relationship. It would take an enormous amount of time and effort to confirm this conjecture and there is no general benefit because it would have to be done for each individual language.

In any case, what translation shows is that there is no one-to-one correspondence of conceptual links and linguistic markers. In my view this confirms my assumption: We all develop a repertoire of conceptual items and connections, and learn to fit them to the syntactic structures that have become customary among the users of a given language. The fit is only APPROXIMATIVE.

If the meanings we have in mind when we speak, and those that are suggested to the listener by our utterance, are essentially subjective, communication is possible only because the experiences from which these meanings have been abstracted are as a rule fairly similar among the speakers of one language. The individual differences of meaning are such that they rarely cause serious disturbances in the everyday use of our language. But, of course, there are exceptions. An experience I had when we came to live in the United Sates in 1966 is a good example. A young man was helping us to move furniture on the first day in our new house. When he was leaving, I heard him say to my wife: “See you later.” I was taken aback and looked at her rather questioningly. We were familiar with the English of Dublin and southern England; and there, the temporal relation indicated in this particular idiom by “later”, was strictly limited to the ONE day and night. It took us some time to learn that for speakers of American English it seems to include an indefinite future.

I have followed one turn of the spiral of meaning and am coming back to Heinz’s paradoxical statement that it is the listener who decides what an utterance means. I first suggested that Shannon’s Theory of Communication confirms the statement, because it shows that it is not meaning that travels with a signal, but rather an instruction to choose a meaning from a pre-established repertoire. I then argued that the way we acquire language shows that the repertoire of meanings which we attribute to words must be developed by each individual speaker on the basis of his or her own subjective experience. I stuck out my neck and asserted that, although it may not often appear on the surface, it is in my view not only semantics but also syntax that children must construct for themselves. No doubt the specific forms of syntax were developed throughout the history of each particular language. But children must create some conceptual links in the course of experience before these links can be attributed to specific syntactic markers of the language they are learning. Once this has happened, the construction of further syntactic elements will be suggested by the situational context of linguistic interactions. On the strength of this exposition I claim that linguistic communication is possible only thanks to the relative sameness of experience and intentions among the speakers of a given language.

These considerations lead to a conclusion that should be sobering for public speakers. Heinz claimed, and I agree, that it is the listener who determines the meaning an utterance has for him or her. I added that the elements that constitute that meanings are abstracted from the listener’s own experience, not from the experience of the speaker. The speaker’s experience is never directly accessible to anyone else. Therefore your understanding of what I have written in the text that Professor Mitterer kindly agreed to read to you, is YOUR interpretation of it in terms of YOUR experience -- and your experiences are unlikely to have been identical with mine.

Consequently, it would be a rather naive illusion for me to believe that you have understood what I have said in this talk exactly as I intended it.

I will be happy if I have given you some things to think about.

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Extract from: The initial knowledge state of college physics students

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Note: This version has been edited to reduce its length. The original version is available also.

An instrument to assess the basic knowledge state of students taking a first course in physics has been designed and validated. Measurements with the instrument show that the student's initial qualitative, common sense beliefs about motion and causes has a large effect on performance in physics, but conventional instruction induces only a small change in those beliefs.

I. INTRODUCTION

Each student entering a first course in physics possesses a system of beliefs and intuitions about physical phenomena derived from extensive personal experience. This system functions as a *common sense theory* of the physical world which the student uses to interpret his experience, including what he uses and hears in the physics course. Surely it must be the major determinant of what the student learns in the course. Yet conventional physics instruction fails almost completely to take this into account. We suggest that this instructional failure is largely responsible for the legendary incomprehensibility of introductory physics.

The influence of common sense beliefs on physics instruction cannot be determined without careful research. Such research has barely gotten started in recent years, but significant implications for instruction are already apparent. Research on common sense beliefs about motion [1-5] has lead to the following general conclusions.

(1) Common sense beliefs about motion are generally incompatible with Newtonian theory. Consequently, there is a tendency for students to systematically misinterpret material in introductory physics courses. (2) Common sense beliefs are very stable, and conventional physics instruction does little to change them.

Previous research into common sense beliefs has focused on isolated concepts. Here we aim for a broader perspective. This article discusses the design and validation of an instrument for assessing the knowledge state of beginning physics students, including mathematical knowledge as well as beliefs about physical phenomena. Measurements with the instrument give firm quantitative support for the general conclusions above. The instrument can be used for instructional purposes as well as further research. In particular, we recommend the instrument for use:

(1) *As a diagnostic test* for identifying and classifying specific [conceptions]. This will be discussed in a subsequent paper.
(2) *To evaluate instruction*. The instrument reliably evaluates the general effectiveness of instruction in modifying a student's initial common sense [conceptions].

II. ASSESSMENT OF A STUDENT'S BASIC KNOWLEDGE

To evaluate physics instruction objectively, we need an instrument to assess a student's knowledge before and after instruction. In the following sections we discuss the design and validation of such an instrument. The instrument consists of two tests: (a) a *physics diagnostic* test to assess the student's qualitative conceptions of common physical phenomena and (b) a *mathematics diagnostic* test to assess the student's mathematical skills. Both tests are intended for use as *pretests* to assess the student's initial knowledge state. The mechanics test is also intended for use as a *post-test* to measure the effect of instruction independent of course examinations.

A. Design of the physics diagnostic test

. . It would be far from sufficient simply to test a student's initial knowledge of Newtonian mechanics. Rather, we need to ascertain the student's common sense knowledge of mechanics, for it is the discrepancy between his common sense concepts and the Newtonian concepts which best describes what the student needs to learn. As Mark Twain once observed, "It's not what you don't know that hurts you.

It's what you know that ain't so!"

Newtonian theory enables us to identify the basic elements in conceptualizations of motion. On one hand, we have the basic *kinematical concepts* of position, distance, motion, time, velocity, and acceleration. On the other hand, we have the basic *dynamical concepts* of inertia, force, resistance, vacuum, and gravity. We take a student's understanding of these basic concepts as the defining characteristics of his basic knowledge of mechanics. Our list of dynamical concepts may look a bit strange, to a physicist, but the particular items on the list were chosen to bring to light major differences between common sense and Newtonian concepts. We refer to a knowledge state derived from personal experience with little formal instruction in physics as a "common sense knowledge state." As a rule, it differs markedly from the "Newtonian knowledge state" of a trained physicist.

To assess the student's basic knowledge of mechanics, we devised the *physics (mechanics) diagnostic test*. (Note: This test is the precursor to the assessment used in the summer course). The test questions were initially selected to assess the student's qualitative conceptions of motion and its causes, and to identify common [conceptions] which had been noted by previous investigators. Various versions of the test were administered over a period of three years to more than 1000 students in college level, introductory physics courses. Early versions required written answers. Answers reflecting the most common [conceptions] were selected as alternative answers in the final multiple-choice version. In this way we obtained an easily graded test which can identify a spectrum of common sense [conceptions].

A student's score on the diagnostic test is a measure of his *qualitative understanding* of mechanics. Statistically it is quite a good measure because of its reliability and predictive validity. We believe also that it is a theoretically sound measure, because the diagnostic test is concerned exclusively with a systematic assessment of basic concepts. One could not expect satisfactory results from the typical "physics achievement test" which tests for knowledge of isolated physical facts.

Table I Physics diagnostic test results by course and professor.

Course		**Pre test %**	**Post test %**	**Gain %**	**Number**
Calc-based intro	A	51	65	13	97
Calc-based intro	B	51	64	13	192
Calc-based intro	C	50	64	13	70
Calc-based intro	D	53	64	11	119
Alg-based intro	E	37	53	15	82
High school	G	30	52	22	24 (honors)
High school	G	30	44	14	25 (general)

III. RESULTS AND IMPLICATIONS FOR TEACHING

The math and physics diagnostic tests have been used to assess the basic knowledge of nearly 1500 students taking University or College Physics at Arizona State University, and of 80 students beginning physics at a nearby high- school.

Table I presents diagnostic test results for classes in University Physics taught by four different professors, and for classes in College Physics taught by two different professors. Considering the nature of the diagnostic test in the Appendix, the average scores on the tests appear to be very low. Interpretation of these results will be our main concern, but for comparison we first take note of the test results for high school students.

We were surprised by the extremely low mechanics pretest scores of the high school students shown in Table I. Their average is only a little above the chance level score of 7.3 on the multiple-choice test. All scores were less than 20, except for one student with the score of 28, who incidentally dropped out of school before completing the physics course. The honors students were selected for high academic performance or achievement test scores, but their physics intuitions are evidently no better than anyone else's. Note that the post-test score of the high school honor students is within the range of pretest scores for the college students in University Physics. However, the post-test score of high school students in General Physics is about two points higher than the pretest scores for students in College Physics. This difference seems to be explained by the fact that about 55% of the students in College Physics had not taken physics before, although those who had averaged only two points better on the physics pretest. At any rate, diagnostic test scores of high school physics students should be investigated further to make sure that the low pretest scores are typical. If they are, then they provide clear documented evidence that physics instruction in high school should have a different emphasis than it has in college. The initial knowledge state is even more critical to the success of high school instruction. The low scores indicate that students are prone to misinterpreting almost everything they see and hear in the physics class.

B. Evaluation of physics instruction
The mechanics diagnostic test can be used as an instrument to evaluate the effectiveness of instruction in improving students' basic knowledge. Of course, instruction may have many worthwhile objectives not measured by the diagnostic test. But improvement of basic knowledge as we defined it above should be the primary objective, since such knowledge is the foundation for the whole conceptual edifice of physics.

The gain in basic knowledge as measured by the mechanics diagnostic test is given in Table I for several different University and College Physics courses. The small values (14%) for the gain indicate that conventional instruction has little effect on the student's basic knowledge state. For the courses in Table I, values of the correlation coefficient for pretest-post-test scores range between 0.60 and 0.76. These high values are statistical indicators of little change in basic knowledge.

All of the courses in Table I were conducted in a lecture-recitation format with 3 or 4 h of lecture and 1 h of recitation each week. The content of the courses in Table I is fairly standard. We refer to instruction on this standard content using the lecture-recitation format described above as *conventional physics instruction* because it is so common in American universities.

Within the format of conventional instruction, wide variations in instructional style are possible. The styles of the four lecturers in University Physics listed in Table I differ considerably. Professor A is a theoretical physicist; his lectures emphasize the conceptual structure of physics, with careful definitions and orderly logical arguments. The other professors are experimental physicists, but with quite different specialties. Professor B incorporates many demonstrations in his lectures, and he expends great time and energy preparing them; he strives especially to help students develop physical intuition. Professor C emphasizes problem solving, and he teaches by example, solving one problem after another in his lectures. Professor D is an experimental physicist teaching introductory physics for the first time; he followed the book closely in his lectures. All four professors are known as good teachers according to informal peer opinion and formal evaluations by students. Indeed, Professor B has twice received awards for outstanding teaching.

Now, Table I shows that **the basic knowledge gain is the same** for all four of the classes in University Physics. All four classes used the same textbook, and covered the same chapters in it. Considering the wide differences in the teaching styles of the four professors, we conclude that the *basic knowledge gain under conventional instruction is essentially independent of the professor*. This is consistent with the common observation among physics instructors that the most strenuous efforts to improve instruction hardly seem to have any effect on general student performance.

The small gain in basic knowledge under conventional instruction is all the more disturbing when one considers the uniformly low levels of the initial knowledge states shown in Table I. This means that throughout the course the students are operating with a seriously defective conceptual vocabulary, which implies that they continually misunderstand the material presented. The student's ability to process information in the course depends mainly on his initial knowledge state and hardly improves throughout the course. This indicates a failure of conventional instruction. The post-test scores in Table I are unacceptably low considering the elementary nature of the test. Even for the A students (about 10% of the students who complete the course) the average post- test score is only about 75%. Whereas, we think that one should not be satisfied with any instruction which fails to bring all students who pass the course above the 75% level. Conventional instruction is far from meeting this standard.

IV. CONCLUSIONS

Our diagnostic test results show that a student's initial knowledge has a large effect on his performance in physics, but conventional instruction produces comparatively small improvements in his basic knowledge. The implications of failure on the part of conventional instruction could hardly be more serious, for we are not talking about a few isolated facts that students failed to pick up. One's basic physical knowledge provides the conceptual vocabulary one uses to understand physical phenomena. A low score on the physics diagnostic test does not mean simply that basic concepts of Newtonian mechanics are missing; it means that alternative [conceptions] about mechanics are firmly in place. If such [conceptions] are not corrected early in the course, the student will not only fail to understand much of the material, but worse, he is likely to dress up his [conceptions] in scientific jargon, giving the false impression that he has learned something about science.

The individual instructor can hardly be blamed for the failure of conventional instruction. The instructor cannot take common sense [conceptions] into account without knowing what they are and how they can be changed. To be sure, every experienced instructor has acquired a store of incidental insights into student [conceptions]. But this by itself leads to incidental improvements of instruction at best, and the hard won insights of one instructor are passed on to others only haphazardly. The full value of such insights can be realized only when they are incorporated into a program of systematic pedagogical research aimed at the development of a practical instructional theory.

We submit that the primary objective of introductory physics instruction should be to facilitate a transformation in the student's mode of thinking from his initial common sense knowledge state to the final Newtonian knowledge state of a physicist. One should hardly expect instruction which fails to take initial common sense knowledge into account to be effective.

a) Now at The Lebanese University II.
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2 A. B. Champagne, L. E. Klopfer, and *I*. H. Anderson, "Factors influencing the learning of classical mechanics," Am. *I*. Phys. **48**, 1074 (1980).
3 A. B. Champagne and L. E. Klopfer, "A causal model of students' achievement in a college physics course," J. Res. Sci. Teach. **19**, 299 (1982).
4 M. McCloskey, A. Caramazza, and B. Green, "Curvilinear motion in the absence of external forces," Science **210**, 1139 (1980).
5 J. Clement, "Students' preconceptions in introductory mechanics," Am. J. Phys. **50**, **66** (1982).
6 G. Anderson *et al., Encyclopedia of Educational Evaluation* (Jossey-Bass, London, 1975).
7 H. T. Hudson and D. Liberman, "The combined effect of mathematics " skills and formal operational reasoning on student performance in the general physics course," Am. J. Phys. **50**, 1117 (1982).
8 W. Wollman and F. Lawrenz, "Identifying potential 'dropouts' from I college physics classes," J. Res. Sci. Teach. **21**, 385 (1984).

An Exercise in Language and Science Learning

Directions: Read the following passage and then without consulting your neighbors answer the questions which follow in complete sentences. Then move on to the next page.

The Montillation of Traxoline

It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is montilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then bracter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescelidge.

1. What is traxoline?

2. Where is traxoline montilled?

3. How is traxoline quaselled?

4. Why is it important to know about traxoline?

Period of a plane pendulum with finite amplitude

Directions: Read the following passage and then without consulting your neighbors answer the questions which follow in complete sentences. Then move on to the next page.

In the limit of small oscillations a plane pendulum behaves like a harmonic oscillator and is isochronous, i.e., the frequency is independent of the amplitude. As the amplitude increases, however, the correct potential energy deviates from the harmonic oscillator form and the frequency shows a small dependence on the amplitude. The small difference between the potential energy and the harmonic oscillator limit can be considered as the perturbation Hamiltonian, and the shift in frequency derived from the time variation of the perturbed phase angle.

Directions: Answer the following questions in complete sentences.

1. Under what conditions does a plane pendulum behave like a harmonic oscillator?

2. What happens to the potential energy when the amplitude increases?

3. What happens to the frequency when the amplitude increases?

4. What is the perturbation Hamiltonian?

5. From what is the frequency shift derived?

Directions: When you and your neighbors have generated answers then compare notes with each other.

Can both of the previous sets of questions be answered? Please explain.

Do you think you would get full credit for your answers to these questions? Please explain.

Would you be able to grade other people's answers without being given the "correct" answers? Please explain.

Do you have to understand what either passage says or what the questions are asking in order to answer the questions? Please explain.

Do you have to understand the answers to the questions in order to generate the answers? Please explain.

How early do you think school students figure out the strategy for answering questions this way? (How much of school is just this?)

Sharing in the Costs of Growth

William G. *Perry, Jr.*

(excerpt from Perry's article that captures an important insight into the nature of constructing new understanding and the consequences of this insight…the costs of growth.)

Over the past several months, some of the staff in our little office have been asking students about how they learn. We just ask, "Tell us about how you experience learning." The usual response is, "You mean *really* learning?" There seems to be a distinction between "just" learning and "really" learning, which is what the students want to talk about. "Really" learning invariably refers to experiences in which one sees the world and oneself in a new and broader light - in short, to those very discoveries that mark the major steps into maturity I have been talking about.

I want to share with you the response of a young woman, a freshman. She said that so far she had been just learning more things at Harvard—"kind of flat"—and that the last time she had really learned was back in high school. She had a social science teacher whom she admired and he introduced to the class one of the Ames experiments with the revolving window. (You know it: There is this odd-shaped window that revolves on an axis and you see it revolve and you *know* it revolves; but then the lighting is changed and the window does not revolve; it oscillates from side to side, and you *know* it oscillates; and then the lighting is changed back and there the window is, revolving.) She said her teacher looked around and said to no one in particular, "So what do you make of *that?*" and no one said anything. "And all of a sudden I *saw.* I mean I saw how much we bring with us to our perception of things, how much we construct our worlds. And I realized that if this was true of windows, how about people? parents? myself, too? The whole world opened up to me, sort of, how everybody makes their own meanings, how different things can look in a different light, so to speak."

She then went on to say how the same experiment had been demonstrated at Harvard as just one more gimmick of perceptual illusion, The interviewer, bored with this complaint, brought her back to that moment in high school: "How did you feel then?" "Oh, it was awful. I mean, my world was shattered. I guess it's sort of naive to use a word like this here, but it was like I lost my innocence. I mean nothing could ever be for sure—like it seems—I mean, again."

Our interviewer then asked, "How come you stayed with it instead of just laughing it off and forgetting it?"

"Oh, that was because of the teacher! You see, I trusted him, and I knew he knew. I mean, we didn't talk about it really, but he just looked at me and I knew he knew—what I'd learned—and what I'd lost! I guess because he knew what I'd lost, I could stay with what I'd seen."

…

Does the teacher have a responsibility here, not only to promote growth and development, but to help people to do something with the losses? (p. 269 – 271)

Perry, William G. Jr. (1978). "Sharing in the Costs of Growth," in *Encouraging Development in College Students*, C. A. Parker (ed), University of Minnesota Press: Minneapolis, pp 267-73.

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CHAPTER 1

Introduction: The Central Puzzles of Learning

Many a person who has tried to master a foreign language in school has thought back wistfully to his (or her*) own learning of his native tongue. Without the help of a grammar book or a trained language instructor, without the sanctions of a course grade, all normal children readily acquire the language spoken in their vicinity. More remarkably, children who are too young to sit at a school desk but who happen to grow up in a polyglot environment can master a number of languages; they even know under which circumstances to invoke each tongue. It is humbling to realize that language learning in early life has operated exquisitely over the millennia, yet linguists are still unable to describe the grammar of any naturally occurring language in a completely satisfactory way.

One can, of course, attempt to dismiss language as a special case. After all, we are linguistic creatures, and perhaps we have special dispensation to speak, just as warblers and chaffinches sing as part of their avian birthright. Or one can stress the immense importance

*For expositional ease, I vary the gender forms from now on.

of language in all human intercourse; perhaps therein lies the solution to the question of why all children successfully master language within a few years of their birth.

Upon examination, however, language turns out to be unexceptional among human capacities. It is simply the most dramatic instance of one puzzle in human learning—the facility with which young humans learn to carry out certain performances that scholars themselves have not yet come to understand. During the first years of life, youngsters all over the world master a breathtaking array of competences with little formal tutelage. They become proficient at singing songs, riding bikes, executing dances, keeping scrupulous track of dozens of objects in their home, on the road, or along the countryside. In addition, though less visibly, they develop powerful theories of how the world works and how their own minds work. They are able to anticipate which manipulations will keep a machine from functioning properly; they can propel and catch balls hurled under various conditions; they are able to deceive someone else in a game even as they can recognize when someone is trying to play a trick on them. They evolve clear senses of truth and falsity, good and evil, beautiful and ugly—senses that may not always be consistent with communal standards but that prove remarkably serviceable and robust.

INTUITIVE LEARNING AND SCHOLASTIC LEARNING

We are faced with another puzzle. The very young children who so readily master symbol systems like language and art forms like music, the same children who develop complex theories of the universe or intricate theories of the mind, often experience the greatest difficulties upon their entry in school. Speaking and understanding language have proved unproblematic, but reading and writing may pose severe challenges; counting and numerical games are fun, but learning mathematical operations can prove vexing, and the higher reaches of mathematics may remain forbidding. Somehow the natural, universal, or intuitive learning that takes place in one's home or immediate surroundings during the first years of life seems of an entirely different order from the school learning that is now required throughout the literate world.

So far, this puzzle is not unfamiliar and has been commented upon

often. Indeed, one might go so far as to claim that schools were instituted precisely to inculcate those skills and conceptions that, while desirable, are not so readily and naturally learned as the intuitive capacities cited above. Accordingly, most of the recent raft of books and reports about the "educational crisis" perseverate on the difficulties students have in mastering the overt agenda of school.

Such a description of the failings of school may be accurate as far as it goes, but in my view it does not go nearly far enough. In this book I contend that even when school appears to be successful, even when it elicits the performances for which it has apparently been designed, it typically fails to achieve its most important missions.

Evidence for this startling claim comes from a by now overwhelming body of educational research that has been assembled over the last decades. These investigations document that even students who have been well trained and who exhibit all the overt signs of success—faithful attendance at good schools, high grades and high test scores, accolades from their teachers—typically do not display an adequate understanding of the materials and concepts with which they have been working.

Perhaps most stunning is the case of physics. Researchers at Johns Hopkins, M.I.T., and other well-regarded universities have documented that students who receive honor grades in college-level physics courses are frequently unable to solve basic problems and questions encountered in a form slightly different from that on which they have been formally instructed and tested.* In a typical example, college students were asked to indicate the forces acting on a coin that has been tossed straight up in the air and has reached the midway point of its upward trajectory. The correct answer is that once the coin is airborne, only gravitational pull toward the earth is present. Yet 70 percent of college students who had completed a course in mechanics gave the same naive answer as untrained students: they cited two forces, a downward one representing gravity and an upward one from "the original upward force of the hand." This response reflects the intuitive or common-sense but erroneous view that an object cannot move unless an active force has somehow been transmitted to it from an original impelling source (in this instance, the hand or arm of the coin tosser) and that such a force must gradually be spent.

*Sources for all quotations, research findings, and allied factual information will be found in the notes beginning on page 265.

Students with science training do not display a blind spot for coin tossing alone. When questioned about the phases of the moon, the reasons for the seasons, the trajectories of objects hurtling through space, or the motions of their own bodies, students fail to evince the understandings that science teaching is supposed to produce. Indeed, in dozens of studies of this sort, young adults trained in science continue to exhibit the very same misconceptions and misunderstandings that one encounters in primary school children—the same children whose intuitive facility in language or music or navigating a bicycle produces such awe.

The evidence in the venerable subject of physics is perhaps the "smoking gun" but, as I document in later chapters, essentially the same situation has been encountered in every scholastic domain in which inquiries have been conducted. In mathematics, college students fail even simple algebra problems when these are expressed in wording that differs slightly from the expected form. In biology, the most basic assumptions of evolutionary theory elude otherwise able students who insist that the process of evolution is guided by a striving toward perfection. College students who have studied economics offer explanations of market forces that are essentially identical to those proferred by college students who have never taken an economics course.

Equally severe biases and stereotypes pervade the humanistic segment of the curriculum, from history to art. Students who can discuss in detail the complex causes of the First World War turn right around and explain equally complex current events in terms of the simplest "good guy–bad guy" scenario. (This habit of mind is not absent from political leaders, who are fond of portraying the most complicated international situations along the lines of a Hollywood script.) Those who have studied the intricacies of modern poetry, learning to esteem T. S. Eliot and Ezra Pound, show little capacity to distinguish masterworks from amateurish drivel once the identity of the author has been hidden from view.

Perhaps, one might respond, these distressing results are simply a further indictment of the American educational system, which has certainly experienced (and perhaps merited) its share of drubbing in recent years. And in fact the majority of the research studies have been carried out with the proverbial American college sophomore. Yet the same kinds of misconceptualizations and lack of understanding that emerge in an American setting appear to recur in scholastic settings all over the world.

What is going on here? Why are students not mastering what they ought to be learning? It is my belief that, until recently, those of us involved in education have not appreciated the strength of the initial conceptions, stereotypes, and "scripts" that students bring to their school learning nor the difficulty of refashioning or eradicating them. We have failed to appreciate that *in nearly every student there is a five-year-old "unschooled" mind struggling to get out and express itself.* Nor have we realized how challenging it is to convey novel materials so that their implications will be appreciated by children who have long conceptualized materials of this sort in a fundamentally different and deeply entrenched way. Early in the century, the work of Freud and other psychoanalysts documented that the emotional life of the young child strongly affects the feeling and behavior of most adults. Now the research of cognitive scientists demonstrates the surprising power and persistence of the young child's conceptions of the world.

Consider examples from two quite different domains. The changing seasons of the year come about as a function of the angle of the earth on its axis in relation to the plane of its orbit around the sun. But such an explanation makes little sense to someone who cannot shake the deeply entrenched belief that temperature is strictly a function of distance from a heating source. In the domain of literature, the appeal of modern poetry resides in its powerful images, its often unsettling themes, and the way in which the poet plays with traditional formal features. Yet this appeal will remain obscure to someone who continues to feel, deep down, that all poetry worthy of the name must rhyme, have a regular meter, and portray lovely scenes and exemplary characters. We are dealing here not with deliberate failures of education but rather with unwitting ones.

Unwitting, perhaps, but not necessarily unnoticed. That some of us may be at least dimly aware of the fragility of our knowledge was brought home to me powerfully in a conversation with my daughter, then a sophomore in college. One day Kerith phoned me, quite distressed. She voiced her concern: "Dad, I don't understand my physics course." Ever eager to assume the role of the patient and sympathetic father, I replied in my most progressive tone, "Honey, I really respect you for studying physics in college. I would never have had the nerve to do that. I don't care what grade you get—it is not important. What's important is that you understand the material. So why don't you go to see your teacher and see if he can help?" "You don't get it, Dad," responded Kerith decisively. "I've never understood it."

Without wishing to burden these words with cosmic importance, I have come to feel that Kerith's comment crystallizes the phenomenon I seek to elucidate in these pages. In schools—including "good" schools—all over the world, we have come to accept certain performances as signals of knowledge or understanding. If you answer questions on a multiple-choice test in a certain way, or carry out a problem set in a specified manner, you will be credited with understanding. No one ever asks the further question "But do you *really* understand?" because that would violate an unwritten agreement: A certain kind of performance shall be accepted as adequate for this particular instructional context. The gap between what passes for understanding and genuine understanding remains great; it is noticed only sometimes (as in Kerith's case), and even then, what to do about it remains far from clear.

In speaking of "genuine understanding" here, I intend no metaphysical point. What Kerith was saying, and what an extensive research literature now documents, is that even an ordinary degree of understanding is routinely missing in many, perhaps most students. It is reasonable to expect a college student to be able to apply in a new context a law of physics, or a proof in geometry, or the concept in history of which she has just exhibited "acceptable mastery" in her class. If, when the circumstances of testing are slightly altered, the sought-after competence can no longer be documented, then understanding—in any reasonable sense of the term—has simply not been achieved. This state of affairs has seldom been acknowledged publicly, but even successful students sense that their apparent knowledge is fragile at best. Perhaps this uneasiness contributes to the feeling that they—or even the entire educational system—are in some sense fraudulent.

Notes

[The numbers in brackets following a short title refer to the page number of its original, complete citation in that chapter.]

Chapter 1. Introduction: The Central Puzzles of Learning

Page

3 The coin-tossing study is described in J. Clement, "Students' Preconceptions in Introductory Mechanics," *American Journal of Physics* 50 (1 [1982]): 66–71; J. Clement, "A Conceptual Model Discussed by Galileo and Used Intuitively by Physics Students," in D. Gentner and A. Stevens, eds., *Mental Models* (Hillsdale, N.J.: Erlbaum, 1983). See other physics references cited in chap. 8, p. 152–59. Examples from other domains are found in chaps. 8 and 9.

4 The occurrence of these misconceptions internationally has been confirmed by my colleagues Lauren Resnick (for Europe) and Giyoo Hatano (for Japan).

11 Different kinds of minds are discussed more fully in H. Gardner, *Frames of Mind* (New York: Basic Books, 1983).

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ERNST VON GLASERSFELD

An Introduction to Radical Constructivism*

The gods have certainty, whereas to us as men conjecture [only is possible].
Alcmaeon[1]

Preliminary Remarks

WITHIN THE LIMITS of one chapter, an unconventional way of thinking can certainly not be thoroughly justified, but it can perhaps be presented in its most characteristic features and anchored here and there in single points. There is, of course, the danger of being misunderstood. In the case of constructivism there is the additional risk that it will be discarded at first sight, because, like skepticism—with which it has certain features in common—it might seem too cool and critical, or simply incompatible with ordinary common sense. The proponents of an idea, as a rule, explain its nonacceptance differently from the way their critics and opponents do. Being myself much involved, it seems to me that the resistance met in the eighteenth century by Giambattista Vico, the first true constructivist, and by Silvio Ceccato and Jean Piaget in the more recent past is not so much due to inconsistencies or gaps in their argumentation as to the justifiable suspicion that constructivism intends to undermine too large a part of the traditional view of the world.

Indeed, one need not enter very far into constructivist thought to realize that it inevitably leads to the contention that man—and man alone—is responsible for his thinking, his knowledge, and therefore also for what he does. Today, when behaviorists are still intent on pushing all responsibility into the environment, and sociobiologists are trying to place much of it into genes, a doctrine may well seem uncomfortable if it suggests that we have no one but ourselves to thank for the world in which we appear to be living. This is precisely what constructivism intends to say—but it says a good deal more. We build this world for the most part unawares, simply because we do not know how we do it. This ignorance is quite unnecessary. Radical constructivism maintains—not unlike Kant in his *Critique*—that the operations by means of which we assemble our experiential world can be explored, and that an awareness of this operating (which Ceccato in Italian so nicely called *consapevolezza operativa*) [4]* can help us do it differently and, perhaps, better.

This introduction, I repeat, will be limited to the exposition of a few aspects. The first section deals with the relation between knowledge and that "absolute" reality that is supposed to be independent of all experience, and I shall try to show that our knowledge can never be interpreted as a picture or representation of that real world, but only as a key that unlocks possible paths for us (see Alcmaeon's fragment).

The second section outlines the beginnings of skepticism and Kant's insight that, because our ways of experiencing are what they are, we cannot possibly conceive of an unexperienced world; it then presents some aspects of Vico's constructivist thought.

The third section explicates some of the main traits of the constructivist analysis of concepts. Some of the many ideas I have taken over from Piaget as well as from Ceccato will be outlined and only sparsely supported by quotations. Piaget's work has greatly influenced and encouraged me during the seventies, and before that the collaboration with Ceccato had provided direction and innumerable insights to my think-

*Bracketed numbers refer to sources at end of the essays.

ing. But for constructivists, all communication and all understanding are a matter of interpretive construction on the part of the experiencing subject, and therefore, in the last analysis, I alone can take the responsibility for what is being said in these pages.

I

The history of philosophy is a tangle of isms. Idealism, rationalism, nominalism, realism, skepticism, and dozens more have battled with one another more or less vigorously and continuously during the twenty-five centuries since the first written evidence of Western thought.

The many schools, directions, and movements are often difficult to distinguish. In one respect, however, any ism that wants to be taken seriously must set itself apart from all those that are already established: It must come up with at least *one* new turn in the theory of knowledge. Often this is no more than a rearrangement of well-known building blocks, a slight shift in the starting point, or the splitting of a traditional concept. The epistemological problem—how we acquire knowledge of reality, and how reliable and "true" that knowledge might be—occupies contemporary philosophy no less than it occupied Plato. The ways and means of the search for solutions have, of course, become more varied and complicated, but the basic question has, almost without exception, remained the same. The way that question was put at the very beginning made it impossible to answer, and the attempts that have since been made could not get anywhere near a solution to the problem.

The philosopher of science Hilary Putnam has recently formulated it like this: "It is impossible to find a philosopher before Kant (and after the pre-Socratics) who was *not* a metaphysical realist, at least about what he took to be *basic* or unreducible assertions" [18]. Putnam explains that statement by saying that, during those 2,000 years, philosophers certainly disagreed in their views about what *really* exists, but their conception of truth was always the same, in that it was tied to the notion of objective validity. A metaphysical realist, thus, is one who insists that we may call something "true" only if it corresponds to an independent, "objective" reality.[2]

On the whole, even after Kant the situation did not change. There were some who tried to take his *Critique of Pure Reason* seriously, but the pressure of philosophical tradition was overwhelming. In spite of Kant's thesis that our mind does not derive laws from nature, but imposes them on it [9], most scientists today still consider themselves "discoverers" who unveil nature's secrets and slowly but steadily expand the range of human knowledge; and countless philosophers have dedicated themselves to the task of ascribing to that laboriously acquired knowledge the unquestionable certainty which the rest of the world expects of genuine truth. Now as ever, there reigns the conviction that knowledge is knowledge only if it reflects the world as it is.[3]

The history of Western epistemology cannot, of course, be described adequately and fairly in a few pages. Given the limits of this essay, it will have to suffice if I pick out the main point in which the constructivism I am proposing differs *radically* from the traditional conceptualizations. This radical difference concerns the relation of knowledge and reality. Whereas in the traditional view of epistemology, as well as of cognitive psychology, this relation is always seen as a more or less picturelike (iconic) correspondence or match, radical constructivism sees it as an adaptation in the functional sense.

In everyday English, this conceptual opposition can be brought out quite clearly by pitting the words *match* and *fit* against one another in certain contexts. The metaphysical realist looks for knowledge that *matches* reality in the same sense as you might look for paint to match the color that is already on the wall you have to repair. In the epistemolo-

[2] "Am Anfang der Erkenntnis steht die Wahrheitsfrage. Ihre Einführung macht das menschliche Erkennen zu einem Wissensproblem."

[3] In *Begründung, Kritik und Rationalität* Spinner provides an excellent comprehensive survey of the thinkers and their arguments that have attacked that still widespread notion, and he documents the general bankruptcy of conventional epistemology [23].

gist's case it is, of course, not color that concerns him, but some kind of "homomorphism," which is to say, an equivalence of relations, a sequence, or a characteristic structure—something, in other words, that he can consider *the same*, because only then could he say that his knowledge is *of* the world.

If, on the other hand, we say that something *fits*, we have in mind a different relation. A key fits if it opens the lock. The fit describes a capacity of the key, not of the lock. Thanks to professional burglars we know only too well that there are many keys that are shaped quite differently from our own but which nevertheless unlock our doors. The metaphor is crude, but it serves quite well to bring into relief the difference I want to explicate. From the radical constructivist point of view, all of us—scientists, philosophers, laymen, school children, animals, and indeed, any kind of living organism—face our environment as the burglar faces a lock that he has to unlock in order to get at the loot.

This is the sense in which the word *fit* applies in the Darwinian and neo-Darwinian theories of evolution. Unfortunately, Darwin himself used the expression *survival of the fittest*. In doing this, he prepared the way for the misguided notion that, on the basis of his theory, one could consider certain things fitter than fit, and that among those there could even be a fittest.[4] But in a theory in which survival is the *only* criterion for the selection of species, there are only two possibilities: Either a species fits its environment (including the other species) or it does not; that is, either it survives or it dies out. Only an external observer who introduces other criteria (e.g., the economy, simplicity, or elegance of the method of surviving), only an observer who deliberately posits values beyond survival, could venture comparative judgments about those items that have already manifested their fitness by surviving.

In this one respect the basic principle of radical construc-

[4] C. F. von Weizsäcker, during a symposium in Bremen (1979), drew attention to the fact that in the German evolutionary literature *fit* is often translated as *tüchtig*, which has the flavor of "prowess" and therefore leads to talk of "the best" or "the toughest."

tivist epistemology coincides with that of the theory of evolution: Just as the environment places constraints on the living organisms (biological structures) and eliminates all variants that in some way transgress the limits within which they are possible or "viable," so the experiential world, be it that of everyday life or of the laboratory, constitutes the testing ground for our ideas (cognitive structures). This applies to the very first regularities the infant establishes in its barely differentiated experience; it applies to the rules with whose help adults try to manage their commonsense world; and it applies to the hypotheses, the theories, and the so-called "natural laws" that scientists formulate in their endeavor to glean from the widest possible range of experiences lasting stability and order. In the light of further experience, regularities, rules of thumb, and theories either prove themselves reliable or they do not (unless we introduce the concept of probability, in which case we are explicitly relinquishing the condition that knowledge must be *certain*).

In the history of knowledge, as in the theory of evolution, people have spoken of "adaptation" and, in doing so, have generated a colossal misunderstanding. If we take seriously the evolutionary way of thinking, it could never be that organisms or ideas adapt to reality, but that reality, by *limiting what is possible*, inexorably annihilates what is not fit to live. In phylogenesis, as in the history of ideas, "natural selection" does not in any positive sense select the fittest, the sturdiest, the best, or the truest, but it functions negatively, in that it simply lets die whatever does not pass the test.

The comparison is, of course, stretched a little too far. In nature, a lack of fitness is invariably fatal; philosophers, however, rarely die of their inadequate ideas. In the history of ideas it is not a question of survival, but one of "truth." If we keep this in mind, the theory of evolution can serve as a powerful analogy: The relation between viable biological structures and their environment is, indeed, the same as the relation between viable cognitive structures and the experiential world of the thinking subject. Both structures *fit*—the first because natural accident has shaped them that way, and the second because human intention has formed them to

attain the ends they happen to attain, ends that are the explanation, prediction, or control of specific experiences.

More important, still, is the epistemological aspect of the analogy. In spite of the often misleading assertions of ethologists, the structure of behavior of living organisms can never serve as a basis for conclusions concerning an "objective" world, that is, a world as it might be prior to experience.[5] The reason for this, according to the theory of evolution, is that there is no causal link between that world and the survival capacity of biological structures or behaviors. As Gregory Bateson has stressed, Darwin's theory is based on the principle of constraints, not on the principle of cause and effect [1]. The organisms that we find alive at any particular moment of evolutionary history, and their ways of behaving, are the result of cumulative *accidental* variations, and the influence of the environment was and is, under all circumstances, limited to the elimination of nonviable variants. Hence the environment can at best be held responsible for extinction, but never for survival. That is to say, an observer of evolutionary history may indeed establish that everything that has died out must in some way have transgressed the range of the viable and that everything he finds surviving is, at least for the time being, viable. To assert this, however, evidently constitutes a tautology (what survives lives) and throws no light whatever on the objective properties of that world that manifests itself in negative effects alone.

These considerations fit the basic problem of the theory of knowledge equally well. Quite generally, our knowledge is useful, relevant, viable, or however we want to call the pos-

[5] Jakob von Uexküll, for example, in his *Streifzüge durch die Umwelten von Tieren und Menschen* (with Georg Kriszat, 1933; reprinted 1970, Fischer, Frankfurt am Main) shows very elegantly that each living organism, because of its own properties, determines an individual environment. Only an independent, wholly extraneous being that does not experience the world but knows it unconditionally and immediately could speak of an "objective" world. For this reason, attempts, such as that by Lorenz, to explain the human concepts of space and time as an "adaptation" but to consider them also as aspects of ontological reality result in a logical contradiction (see Konrad Lorenz, 1941, Kants Lehre vom Apriorischen im Lichte gegenwärtiger Biologie, *Blätter für Deutsche Philosophie*, 15, 94–125).

itive end of the scale of evaluation, if it stands up to experience and enables us to make predictions and bring about or avoid, as the case may be, certain phenomena (i.e., appearances, events, experiences). If knowledge does not serve that purpose, it becomes questionable, unreliable, useless, and is eventually devaluated as superstition. That is to say, from the pragmatic point of view, we consider ideas, theories, and "laws of nature" as structures that are constantly exposed to our experiential world (from which we derived them), and either they hold up or they do not. Any cognitive structure that serves its purpose in our time, therefore, proves no more and no less than just that—namely, given the circumstances we have experienced (and determined *by* experiencing them), it has done what was expected of it. Logically, this gives us no clue as to how the "objective" world might be; it merely means that we know *one* viable way to a goal that we have chosen under specific circumstances in our experiential world. It tells us nothing—and cannot tell us anything—about how many other ways there might be or how that experience that we consider the goal might be connected to a world *beyond* our experience. The only aspect of that "real" world that actually enters into the realm of experience is its constraints, or, as Warren McCulloch, one of the first cyberneticists, so dramatically said, "to have proved a hypothesis false is indeed the peak of knowledge" [14].

Radical constructivism, thus, is *radical* because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all and finds himself in full agreement with Piaget, who says, "Intelligence organizes the world by organizing itself" [17].

For Piaget, organization is always the result of a necessary interaction between conscious intelligence and environment, and because he considers himself primarily a philosopher of biology, he characterizes that interaction as "adaptation." With that, too, I agree, but after what was said in the preceding pages about the process of evolutionary

selection, it should be clear that the adaptive fit must never be interpreted as a correspondence or homomorphism. With regard to the basic question, how cognitive structures or knowledge might be related to an ontological world beyond our experience, Piaget's position is somewhat ambiguous. Frequently one has the impression that, in spite of his massive contributions to constructivism, he still has a hankering for metaphysical realism. In that, of course, he is not alone. Donald Campbell, who has provided an excellent survey of proponents of "evolutionary epistemology" since Darwin, writes, "The controversial issue is the conceptual inclusion of the real world, defining the problem of knowledge as the fit of data and theory to that real world" [3]. In his conclusion he then declares that the evolutionary epistemology, which he and Karl Popper represent, "is fully compatible with an advocacy of the goals of realism and objectivity in science." But the theory of which he provided an extremely lucid exposition points in the opposite direction [22].

In this first section, I have tried to show that the notion of correspondence or match between knowledge and reality, a notion that is indispensable for realism, cannot possibly be derived from, let alone substituted for, the evolutionary notion of "fit." In the second section I shall provide at least an approximate account of the links between radical constructivism and the history of epistemology, from which one may see that this constructivism is not quite as radical as it appears at first sight.

II

Doubts concerning the correspondence between knowledge and reality arose the moment a thinking individual became aware of his own thinking. Already Xenophanes, one of the earliest of the pre-Socratics, said that no man has ever seen certain truth, nor will there ever be one who knows about the gods and the things of the world, "for if he succeeds to the full in saying what is completely true, he himself is nevertheless unaware of it; opinion (seeming) is fixed by fate upon all things" [6].

Something that could be "seen" would have to *be there* before a glance can fall upon it—and knowledge thus becomes a reflection or picture of a world that is there, that is, exists, before any consciousness sees it or experiences it in any other way. The stage was set, and with it the dilemma that has determined Western epistemology ever since the sixth century B.C. "Metaphysical realism" [18] given that scenario, is not one philosophical stance among others, but it is inherently predetermined as the only possible one. As Maturana has made particularly clear, "the a priori assumption that objective knowledge constitutes a description of that which is known . . . begs the questions '*What is to know?* and *How do we know?*' " [15] By taking for granted that knowledge must reflect reality, traditional epistemology has created for itself a dilemma that was as inevitable as it was unsolvable.

If knowledge is to be a description or image of the world as such, we need a criterion that might enable us to judge when our descriptions or images are "right" or "true." Thus, with the scenario in which man is born into a ready-made independent world as a "discoverer" with the task of exploring and "knowing" that reality in the truest possible fashion, the path of skepticism is there from the outset. The notion of "appearance" and "semblance" that, according to Xenophanes, is attached to all human knowledge, was elaborated and applied above all to perception by Pyrrho's school and, later, by Sextus Empiricus; and the unanswerable question as to whether, or to what extent, any picture our senses "convey" might correspond to the "objective" reality is still today the crux of the entire theory of knowledge. Sextus used, among other things, an apple as an example. To our senses it appears smooth, scented, sweet, and yellow, but it is far from self-evident that the real apple possesses these properties, just as it is not at all obvious that it does not possess other properties as well, properties that are simply not perceived by our senses [21].

The question is unanswerable because, no matter what we do, we can check our perceptions only by means of other perceptions, but never with the apple as it might be *before* we perceive it. The skeptics' argument made the philoso-

pher's life difficult for some 2,000 years [19]. Then Kant added a second, even more troublesome argument. By considering space and time aspects of our way of experiencing, he shifted them out of reality into the realm of the phenomenal, and in doing so he made questionable not only the sensory properties but also the "thinghood" of the apple. Thus not only are the apple's smoothness, scent, sweetness, and color doubtful, but we can no longer be sure that there actually exists an object such as we experience it, separated from the rest of the world as a unitary whole or "thing."

This second doubt is indeed more serious in its consequences than that concerning the reliability of our senses: It undermines any representation of objective structure in the real world and thus inevitably raises the questions as to why and, above all, *how* it comes about that we search for and can also find a structure in our experiential world when such a structure may not be given by reality. In other words, if Kant's statement is correct and our experience can teach us nothing about the nature of things in themselves [10] how, then, can we explain that we nevertheless experience a world that is in many respects quite stable and reliable?

This is the main question with which radical constructivism attempts to deal, and the answer it suggests was prepared, at least in its main lines, by Giambattista Vico in 1710, more than half a century before Kant:

> As God's truth is what God comes to know as he creates and assembles it, so human truth is what man comes to know as he builds it, shaping it by his actions. Therefore science (*scientia*) is the knowledge (*cognitio*) of origins, of the ways and the manner how things are made. [25]

Vico's battle cry, "*Verum ipsum factum*"—the truth is the same as the made (*factum* and *fact* both come from the Latin *facere*, to make!)—has been quoted quite frequently since Vico was rediscovered in our century as a cultural historian and philosopher of history. His revolutionary epistemological ideas, however, are rarely mentioned, let alone explicated. According to him, the only way of "knowing" a thing is to have made it, for only then do we know what its components are and how they were put together. Thus God knows his creation, but we cannot; we can know only what we ourselves construct. Vico even uses the word *operation* and thus preempts the main term launched by constructivists such as Dewey, Bridgman, Ceccato, and Piaget in our century.

Vico, of course, still tries to establish a connection between human cognitive construction and God's creation. Reading his treatise on metaphysics, one gets the impression that he occasionally gets frightened of his own ideas. Although the theory of knowledge he has developed is logically closed because man's knowledge is seen as man's construction and does not (and could not) require God's ontological creation, Vico is reluctant to stress that independence. Because of this reluctance, his picture of the world could be seen as a counterpart to Berkeley's metaphysics. For Berkeley, the principle "*esse est percipi*" (to be is to be perceived) does the same trick as Vico's statement that God knows everything because he has made everything. For both, ontology is assured through God's activities. Vico, however, also opens another way toward ontology that I find much more acceptable because it does not involve any form of rational realism. He suggests that mythology and art approach the real world by means of symbols. They, too, are *made*, but the interpretation of their meaning provides a kind of knowledge that is different from the rational knowledge of construction.

For us, the important difference between Vico and Berkeley, as well as later idealists, is that Vico considers man's rational knowledge and the world of rational experience simultaneous products of man's cognitive construction [26]. Thus Vico's "knowledge" is what today we might call an awareness of the operations that result in our experiential world. Though Berkeley says "that all the choir of heaven and furniture of earth, in a word all those bodies which compose the mighty frame of the world, have not any subsistence without a mind, their *being* is to be perceived or known," [2] and thus presupposes the activity of the intellect, his accent always lies on the *being*, whereas Vico invariably stresses human *knowledge* and its construction.[6]

There can be no doubt that Vico's explicit use of the word *facere* and his constant reference to the composing, the putting together, and, in short, the active construction of all knowledge and experience come very much closer to Piaget's genetic epistemology and to modern constructivism in general than did Berkeley. Nowhere does this become clearer than in a statement with which Vico anticipated the epistemological attitude of some of today's philosophers of science: "Human knowledge is nothing else but the endeavour to make things correspond to one another in shapely proportion" [29].

Our main question was how it might come about that we experience a relatively stable and reliable world in spite of the fact that we are unable to ascribe stability, regularity, or any other perceived property to an objective reality. Vico does not answer this question; rather, he makes it superfluous and meaningless. If, as he says, the world that we experience and get to know is necessarily constructed by ourselves, it should not surprise us that it seems relatively stable. To appreciate this, it is necessary to keep in mind the most fundamental trait of constructivist epistemology, that is, that the world which is constructed is an experiential world that consists of experiences and makes no claim whatsoever about "truth" in the sense of correspondence with an ontological reality. Hence Vico's position is in this respect similar to that of Kant, who says, "Nature, therefore . . . is the collective conception of all objects of experience" [11]. For Kant, it is the "raw material of sensory impressions" that "the mind's activity . . . processes so that it becomes knowledge of objects that we call experience" [12]. In other words, experience as well as all objects of experience are under all circumstances the result of *our* ways and means of experiencing and are necessarily

[6] Berkeley's *Treatise* and Vico's *De Antiquissima* were both published in 1710 and are in some ways remarkably parallel, yet the authors knew nothing of one another. They met a few years later in Naples, but, to my knowledge, there is no record of the discussions that—it would seem inevitable—they must have had.

structured and determined by space and time and the other categories derived from these. The processing of the raw material in Kant's system is governed *automatically* by space and time (without which *no* experience would be possible) and the other categories that, for that very reason, are called a priori. The a priori, therefore, might be considered the technical description of the organism's experiential capability. The a priori describes the framework within which such an organism operates, but it does not tell us what the organism does, let alone why it does it. "A priori" is tantamount to "built in" or "innate," and Kant's justification of it leads, albeit in a roundabout fashion, to God and to a Platonic mythology of ideas. In this respect, Vico is more modern and more prosaic. Of the category of causality, for instance, he says, "If true means to have been made, then to prove something by means of its cause is the same as causing it" [27]. This notion (which has been rediscovered, no doubt without any knowledge of Vico, by the modern constructivist mathematicians) has, as Vico realized, a remarkably wide range of application.

Causes thus originate in the putting together of individual elements; that is, they originate from an experiencer's active operating, such that, for instance, "the determinate (i.e., causally determined) form of the object springs from the order and the composition of elements" [28].[7] Quite generally this means that the world we experience is, and must be, as it is, because *we* have put it together in that way. While the way in which that composition takes place is determined by the a priori for Kant, there are no immutably built-in principles in Vico's system that determine our ways of experiencing, thinking, and constructing. Instead, such constraints as we encounter spring from the history of our construction, because at any moment whatever has been done limits what can be done now [20].

To sum up Vico's thought, the construction of knowledge,

[7] George A. Kelly, founder of the psychology of personal constructs, independently came to the same conclusion: "To the living creature, then, the universe is real, but it is not inexorable unless he chooses to construe it that way" (*A Theory of Personality*. W. W. Norton, New York, p. 8).

for him, is not constrained by the goal of (impossible) correspondence with an "objective" reality that can neither be experienced nor known. It is, however, constrained by conditions that arise out of the material used, which, be it concrete or abstract, always consists of the results of prior construction. With this idea of consistency within certain restraints that replaces the iconic notion of "truth," Vico, without knowing it, anticipated the basic principle of *viability* in the constructivist theory of knowledge.

As elegant as his system is, it still leaves open two questions: First, what are the conditions under which a new construct will be considered compatible with what has already been constructed? Second, why should any organism undertake the task of cognitive construction? The third section will describe an attempt to answer these questions.

III

In traditional theories of knowledge, the activity of "knowing" is taken as a matter of course, an activity that requires no justification and which functions as an initial constituent. The knowing subject is conceived of as a "pure" entity in the sense that it is essentially unimpeded by biological or psychological conditions. The radical constructivist epistemology quite deliberately breaks that conventional framework and commits what professional philosophers, more or less disparagingly, dismiss as "psychologism." The deliberations that have led me to this somewhat iconoclastic step derive from what was said in the first two sections as soon as one considers them jointly.

First, there is the realization that knowledge, that is, what is "known," cannot be the result of a passive receiving, but originates as the product of an active subject's activity. This activity is, of course, not a manipulating of "things in themselves," that is, of objects that could be thought to possess, prior to being experienced, the properties and the structure the experiencer attributes to them. We therefore call the activity that builds up knowledge "operating," and it is the operating of that cognitive entity which, as Piaget has so succiently formulated, organizes its experiential world by organizing itself. Epistemology thus becomes the study of *how* intelligence operates, of the ways and means it employs to construct a relatively *regular* world out of the flow of its experience. The function of the intellect, however, has always been a matter that interested psychology—and the greater the emphasis put on active operating, the more psychological the investigation becomes. If, besides, a developmental view is taken and phylogenetic or ontogenetic concepts are applied, we are decidedly in the area of "genetic epistemology," an area that metaphysical realists take great pains to avoid, because in their view the theory of knowledge must on no account be adulterated by biological or physiological considerations [16].

If, however, as Alcmaeon already suggested, the human activity of knowing cannot lead to a certain and true picture of the world, but only to conjectural interpretation, then that activity can be viewed as the creating of keys with whose help man unlocks paths toward the goals he chooses. This means that the second question we asked at the end of the preceding section, namely, why a cognitive activity should take place, is inextricably connected with the first one—because the success of a key does not depend on finding a lock into which it might fit, but solely on whether or not it opens the way to the particular goal we want to reach.

Constructivism necessarily begins with the (intuitively confirmed) assumption that all cognitive activity takes place within the experiential world of a goal-directed consciousness. Goal directedness, in this context, has, of course, nothing to do with goals in an "external" reality. The goals that are involved here arise for no other reason than this: 'A cognitive organism evaluates its experiences, and because it evaluates them, it tends to repeat certain ones and to avoid others. The products of conscious cognitive activity, therefore, always have a purpose and are, at least originally, assessed according to how well they serve that purpose. The concept of purposiveness, however, presupposes the assumption that it is possible to establish regularities in the experiential world. Hume's argument describes the situation

perfectly: "For all Inferences from Experience suppose, as their Foundation, that the future will resemble the past. . . . If there be any Suspicion, that the Course of Nature may change, and that the past may be no Rule for the future, all Experience becomes useless, and can give rise to no Inferences or Conclusions" [8]. This belief is inherent in everything we consider alive.

The concept of "nature," for Hume no less than for Kant, was the totality of the objects of experience [11]. That is to say, whatever we infer from our experience—that is, whatever we call *inductive*—necessarily concerns our experience and not that mythical experiencer-independent world of which metaphysical realists dream.

The second insight the constructivist approach allows us to formulate concerns the nature of the regularities that a cognitive organism finds or, rather, produces in its experiential world. In order to claim of anything whatever that it is regular, constant, or in any sense *invariant*, a comparison has to be made. That is to say, something that has already been experienced is put in relation to a second experience which, in the experiential sequence, does not coincide with the first experience. This "putting in relation," irrespective of whether the comparison yields similarity or difference, will give rise to one of two essentially different concepts: equivalence and individual identity. The confusion of these two mutually incompatible concepts is greatly enhanced by the fact that, in English, the word *same* is quite indiscriminately used for both. The confusion, however, is a conceptual one, because in other languages that originally provided two distinct expressions (e.g., in German, *das Gleiche* and *dasselbe;* in Italian, *stesso* and *medesimo*) present-day usage is no less indiscriminate. Yet if we want to understand one of the most elementary building blocks of cognitive construction, we must clearly distinguish the two concepts involved.

As Piaget has shown, the concepts of equivalence and individual identity are not given a priori (innate), but have to be built up; and every "normal" child does, in fact, build them up within the first two years of life [17]. The development of a representational capability is crucial in this achievement. On the one hand, it is the capability of representing to oneself a past perception or experience that makes possible the comparison between it and a present experience; and on the other hand, this same capability of representation makes it possible for us to consider repeated perceptions, and especially groups of repeated perceptions, as *objects* and to place them into a space that is independent of the subject's own motion and into a time independent of the subject's own stream of experience. Hand in hand with this development, there arise two possible ways of comparing. Two experiential items can always be "externalized" as two mutually independent objects; but two experiential items can also be considered two experiences of one and the same individually "existing" object. This distinction does not depend on the result of a comparison between the two experiences, but is determined by the conceptual character of the two items being compared. If that comparison leads to a verdict of "sameness," we have either two objects that are equivalent with respect to the properties examined in the comparison, or *one* object which has remained unchanged during the interval between the two experiences. If, instead, the comparison leads to a verdict of "difference," we have either two objects with different properties or one object that has *changed* since our preceding experience of it.

In our everyday practice of experience, we do, of course, establish contexts that propel us toward one or the other conceptualization, respectively, without consciously having to choose between equivalence and individual identity each time. I have shown elsewhere that there are cases of indecision and how we then try to determine individual identity by the more or less plausible demonstration of some form of continuity [7]. In the present context, I merely want to stress that any such continuity in the existence of an individual object is under all circumstances the result of operations carried out by the cognizing subject and can never be explained as a given fact of objective reality.

No one uses these conceptual possibilities more skillfully than the professional magician. During a performance he may, for instance, request a spectator's ring, toss the ring across the room to his assistant, and then let the stunned

spectator find his ring in his own coat pocket. The magic consists in directing the spectators' perception in such a way that they unwittingly construct an individual identity between the first experience of the ring and the experience of the thrown object. Once this has been done, it would indeed require magic to transfer the ring from the assistant to the spectator's pocket. Another case is that of the red ribbon that the magician cuts into little pieces and then—literally with a flick of his hand—produces once more as one whole piece.

A similar, often cited example is the movie film that, depending on the conditions of perception, we see as a sequence of individually different images or as *one* continuously moving image. Irrespective of any "real" horse that may or may not have trotted somewhere at some time and been filmed while doing so, when the film is presented to us, we ourselves must construct the motion by constituting a *continuous* change of one horse from the succession of images. The fact that we do this unconsciously cannot alter the fact that we have to do it in order to perceive the motion.

No less constructed are the judgments of sameness and difference in the realm of perceptual objects. As I indicated above, "sameness" is always the result of an examination with regard to specific properties. Two eggs may be considered the same because of their shape, size, or color, or because they come from the same hen, but there will be a pungent difference between them if one was laid yesterday and the other six weeks ago. A field mouse and an elephant are different in many ways, but they will be considered the same whenever we want to distinguish mammals from other animals. Finally, all eggs, all animals, and indeed all objects that I have ever seen or imagined are the same in the one respect that I have isolated them as bounded, unitary objects in the total field of my experience. In these cases, as in all conceivable ones, it should be clear that the criteria by means of which sameness or difference is established are criteria which are created and chosen by the judging, experiencing subject and cannot be ascribed to an experiencer-independent world.

For an understanding of radical constructivism, it is even more important to appreciate the subject's active operating that gives rise to regularities and invariances in the experiential world. Both regularity and constancy presuppose repeated experience, and repetition can be established only on the basis of a comparison that yields a judgment of sameness. Sameness, however, as we have seen, is always relative: Objects, and experiences in general, are the "same" with respect to the properties or components that have been checked in a comparison. Hence an experience that consists, for instance, of the elements *a*, *b*, and *c* can be considered the same as an experience consisting of *a*, *b*, *c*, and *x*, as long as *x* is not taken into account. This, in fact, is the principle of *assimilation*. In a context in which only the components or properties *a*, *b*, and *c* matter, every object that contains *a*, *b*, and *c* is acceptable. Indeed, no such object will be discriminable from other objects that also contain *a*, *b*, and *c*, as long as no other elements are included in the comparison. The situation, however, changes if an object, in spite of the fact that it manifests *a*, *b*, and *c*, turns out to behave in a way that is different from the behavior that, on the basis of prior experience, is expected of *a–b–c* objects. If this happens, it causes a disturbance (perturbation) that can lead to the examination of other properties or components. This opens the way toward a discrimination of the disturbing object (i.e., the object that is no longer acceptable) on the basis of some hitherto disregarded element *x*. We then have an instance of the principle of *accommodation*, the mainstay of Piaget's theory within the framework of action schemes and of his analysis of cognitive development. Here I merely want to emphasize that in this principle, too, the concept of "fit" is incorporated, because here, too, it does not matter what an object might be like in "reality" or from an "objective" point of view; what matters is exclusively whether or not it performs or behaves in the way that is expected of it, that is, whether or not it fits.

If repetition can be constructed on the basis of such comparisons, it should be clear that the same holds for all kinds of regularities. All concepts that involve repetition are dependent on a particular point of view, namely, *what* is being considered, and with respect to *what* sameness is demanded. Given that the raw material of the experiential world is sufficiently rich, an assimilating consciousness can construct regularities and order even in a chaotic world. The extent to which this will succeed depends far more on the goals and the already constructed starting points than on what might be given in a so-called "reality." But in our experience, which is always determined by the goals we have chosen, we always tend to ascribe the obstacles we meet to a mythical reality rather than to the way in which we operate.

A bricklayer who builds exclusively with bricks must sooner or later come to the conclusion that wherever there is to be an opening for a door or window, he has to make an arch to support the wall above. If this bricklayer then believes he has discovered a law of an absolute world, he makes much the same mistake as Kant when he came to believe that all geometry had to be Euclidean. Whatever we choose as building blocks, be it bricks or Euclid's elements, determines limiting constraints. We experience these constraints from the "inside," as it were, from the brick or the Euclidean perspective. We never get to see the constraints of the world, with which our enterprises collide. What we experience, cognize, and come to know is necessarily built up of our own building blocks and can be explained in no other way than in terms of our ways and means of building.

Summary

Language inexorably forces us to present everything as a sequence. The three sections of this essay, thus, will have to be read one after the other, but this inevitable succession should not be understood as a logically necessary order. What is contained in each of these sections could be outlined only very approximately as independent themes, because, in constructivist thought, each is so closely interwoven with the other principal themes that, presented separately, each would seem to be little more than a finger exercise. Singly, the arguments I have presented here certainly cannot create a new way of thinking about the world; if they can do that at all, it will be through the fabric of their interrelations.

The conceptual analysis shows, on the one hand, that a consciousness, no matter how it might be constituted, can "know" repetitions, invariances, and regularities only as the result of a comparison; on the other hand, it shows that there must always be a decision preceding the comparison proper, whether the two experiences to be compared should be considered occurrences of one and the same object or of two separate ones. These decisions determine what is to be categorized as "existing" unitary objects and what as relationships between them. Through these determinations, the experiencing consciousness creates *structure* in the flow of its experience; and this structure is what conscious cognitive organisms experience as "reality"—and since this reality is created almost entirely without the experiencer's awareness of his or her creative activity, it comes to appear as given by an independently "existing" world.

This view is not particularly new. Skeptics have tended toward it ever since Pyrrho, and the theoretical physicists of our time come close to it in their own terms (they have to ask more and more often whether they are discovering laws of nature or whether it is not, rather, their sophisticated preparation of experimental observations that forces nature into a preconceived hypothesis). However, as long as we remain, in our innermost belief, "metaphysical realists" and expect that knowledge (the scientific as well as the everyday) provide a "true" picture of a "real" world that is supposed to be independent of any knower, the skeptic cannot but seem a pessimist and spoilsport because his arguments perpetually draw attention to the fact that no such "true" knowledge is possible. The realist may, of course, remain a realist in spite of this and say that the skeptic's arguments can be disregarded simply because they contradict common sense. If, however, he takes these arguments seriously, the realist must retreat to some form of subjective idealism, and this retreat inevitably leads to solipsism, that is, to the belief that there exists no world at all apart from the conceiving mind of the subject.

On the one hand, this situation seems inevitable because of the unimpeachable logic of the skeptical arguments; on

the other hand, we are intuitively convinced and find constant experiential confirmation that the world is full of obstacles that we do not ourselves deliberately place in our way. To resolve the situation, then, we must find our way back to the very first steps of our theories of knowledge. Among these early steps there is, of course, the definition of the relationship between knowledge and reality, and this is precisely the point where radical constructivism steps out of the traditional scenario of epistemology. Once knowing is no longer understood as the search for an iconic representation of ontological reality, but, instead, as a search for *fitting* ways of behaving and thinking, the traditional problem disappears. Knowledge can now be seen as something that the organism builds up in the attempt to order the as such amorphous flow of experience by establishing repeatable experiences and relatively reliable relations between them. The possibilities of constructing such an order are determined and perpetually constrained by the preceding steps in the construction. This means that the "real" world manifests itself exclusively there where our constructions break down. But since we can describe and explain these breakdowns only in the very concepts that we have used to build the failing structures, this process can never yield a picture of a world which we could hold responsible for their failure.

Once this has been fully understood, it will be obvious that radical constructivism itself must not be interpreted as a picture or description of any absolute reality, but as a possible model of knowing and the acquisition of knowledge in cognitive organisms that are capable of constructing for themselves, on the basis of their own experience, a more or less reliable world.

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HEINZ VON FOERSTER

On Constructing a Reality*

Draw a distinction!

G. Spencer Brown [1]

The Postulate

I AM SURE YOU remember the plain citizen Jourdain in Molière's *Le Bourgeois Gentilhomme* who, nouveau riche, travels in the sophisticated circles of the French aristocracy and who is eager to learn. On one occasion his new friends speak about poetry and prose, and Jourdain discovers to his amazement and great delight that whenever he speaks, he speaks prose. He is overwhelmed by this discovery: "I am speaking Prose! I have always spoken Prose! I have spoken Prose throughout my whole life!"

A similar discovery has been made not so long ago, but it was neither of poetry nor of prose—it was the environment that was discovered. I remember when, perhaps ten or fifteen years ago, some of my American friends came running to me with the delight and amazement of having just made a great discovery: "I am living in an Environment! I have always lived in an Environment! I have lived in an Environment throughout my whole life!"

However, neither M. Jourdain nor my friends have as yet made another discovery, and that is when M. Jourdain speaks,

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